PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B63B 1/20 | A1

(11) International Publication Number: WO 98/08732

(43) International Publication Date: 5 March 1998 (05.03.98)

(21) International Application Number: PCT/US97/14987

(22) International Filing Date: 26 August 1997 (26.08.97)

(30) Priority Data:
08/703,897 27 August 1996 (27.08.96) US

(71) Applicant: NEWPORT TECHNOLOGIES, LTD. [US/US]; 1151 Hilltop Drive, Redding, CA 96003 (US).

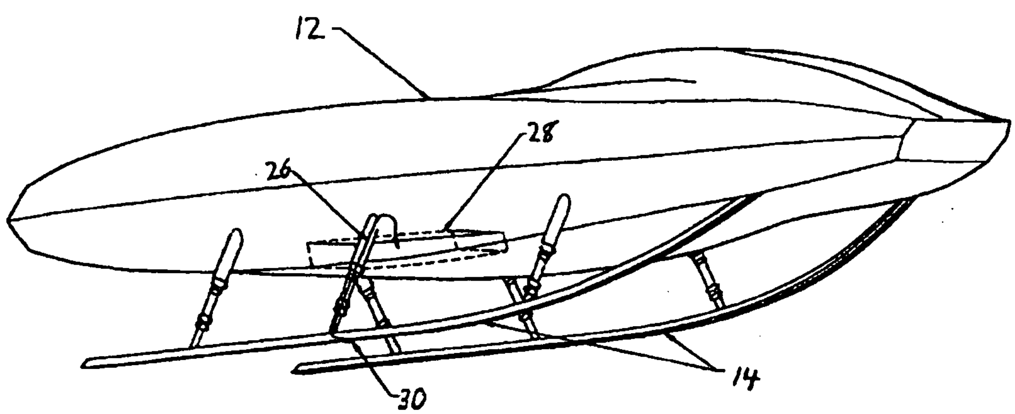
(72) Inventors: ROAKE, Richard, J.; 239A Eustis Avenue, Newport, RI 02840 (US). BAKER, Stephen, C.; 881 Fort Getty Road, Jamestown, RI 02835 (US).

(74) Agent: MROSE, James, E.; Fish & Richardson, P.C., 225 Franklin Street, Boston, MA 02110-2804 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: HYDROSKIING MARINE VESSEL



(57) Abstract

A marine vessel includes a buoyant vessel body (12), a propulsive device, and at least one planing element (14). The planing element lifts the buoyant vessel body upward and out of contact with water throughout prolonged high-speed travel. The ratio of the planing element area to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds is less than 1. The length of the planing element is at least 20 times its breadth. At least one of a plurality of attachment mechanisms (26) attached between the planing element and the buoyant vessel body is controllably adjustable in length so as to adjust an angle of attack of the planing element with respect to water. A deadrise angle adjustment mechanism (42) controllably adjusts a deadrise angle of the planing element with respect to water. The buoyant vessel body includes a ballast tank (28), and ballast piping connects the ballast tank with a ballast intake valve (30).

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

HYDROSKIING MARINE VESSEL

Background of the Invention

This invention relates to marine vessels having hydroskis and more particularly relates to hydroskiing marine vessels capable of travel at very high speeds with active control of pitch, yaw, and roll and dynamic damping of impact loadings, wave loadings, and vibrations.

Marine vessels may be fitted with hydroskis for the purpose of lifting the buoyant vessel body out of contact with water at sufficiently high speeds, due to planing action of the hydroskis, thereby reducing hydrodynamic drag. Such a marine vessel can be steered by appropriate vectoring of the thrust of its propulsion system. During hydroskiing operation the hydroskis are displaced downwardly with respect to the buoyant vessel body but during low-speed operation of the marine vessel the hydroskis may be retracted upward such that the lower surfaces of the hydroskis form part of the lower surface of the hull of the marine vessel.

Summary of the Invention

One aspect of the invention features a marine vessel that includes a buoyant vessel body, a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed, and at least one planing element attached to the buoyant vessel body. The planing element or elements lift the buoyant vessel body upward and out of contact with water throughout prolonged high-speed travel of the marine vessel, by virtue of lifting action due to planing. The planing element or elements have a length and breadth that, when multiplied, define a planing element area (A_p). Each of the planing elements supports a weight that, when divided by mass density of water, defines a volumetric equivalent of the weight supported by the planing element (∇). The ratio

of the planing element area to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds $A_p/(\nabla^{2/3})$ is less than 1.

Applicant believes that when $A_p/(\nabla^{2/3})$ is less than 1 the coefficient of drag (C_d) due to planing of a hydroskiing marine vessel should be relatively low, given the froude number [F_n = speed/(gravitational acceleration x hull length)^{½}] at which such a vessel would be expected to operate. Because the coefficient of drag is low, such a vessel should be able to operate at high speeds with high energy efficiency.

According to another aspect of the invention the length of each of the planing elements is at least 20 times the breadth of the planing element. Applicant believes that the ratio of lift to drag (L/D) due to planing of a hydroskiing marine vessel is relatively high where the aspect ratio (AR) of breadth to length of the planing element is sufficiently low, assuming that the angle of attack (α) between the skis and the water is also sufficiently low. The high lift to drag ratio enables the marine vessel to operate at high speeds with high energy efficiency.

According to another aspect of the invention there are a plurality of attachment mechanisms attached to the planing element or elements and the buoyant vessel body. The attachment mechanisms have strength and rigidity sufficient to transmit lifting forces from the planing element or elements to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water. At least one of the attachment mechanisms is controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with the water, so as to adjust an angle of attack (α) of the planing

element or elements with respect to the water during the high-speed travel.

The ability to adjust the angle of attack (α) of the planing element or elements with respect to the water is advantageous because lift is a function of the angle of attack. In particular, lift (L) is equal to $\frac{1}{2}\rho v^2 A_W (dC_L/d\alpha)\alpha(\cos\beta)$, where ρ is the density of water, v is velocity of the marine vessel, A_W is the wetted area of the planing element at a given point in time, C_L is coefficient of lift, and β is the deadrise angle of the planing element. By appropriate adjustment of the angle of attack (α) it is possible to maintain a substantially constant lift, in a planing condition, over a broad range of speeds.

Another aspect of the invention provides a deadrise angle adjustment mechanism attached to the planing element or elements that controllably adjusts a deadrise angle (β) of the planing element or elements with respect to the water during the high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with the water. The ability to adjust the deadrise angle (β) of the planing element or elements with respect to the water is advantageous because lift is a function of the deadrise angle, as is discussed above. Thus, by appropriate adjustment of the deadrise angle (β) it is possible to maintain a substantially constant lift, in a planing condition, over a broad range of speeds.

Another aspect of the invention features one or more ballast tanks within the buoyant vessel body, one or more ballast intake valves, and ballast piping connecting the ballast tank or tanks with the ballast intake valve or valves. The ballast intake valve or valves controllably receive water during high-speed travel of the marine vessel to fill the ballast tank or tanks

through the ballast piping. The ballast tank or tanks make it possible to compensate for spent fuel with intake of water. By compensating for lost weight due to spent fuel it is possible to prevent undue lifting of the buoyant vessel body due to planing, which would result in inefficient operation of the marine vessel.

Another aspect of the invention features a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves, and a control system connected to the sensor system and to the propulsive device and configured to actively vector thrust from the propulsive device in response to the signal information from the sensor system. The active vectoring of thrust compensates for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

The sensor system may include, for example, an accelerometer that directly measures motion of the marine vessel due to waves, or a wave sensor that detects water waves before the waves interact with the marine vessel, or both of the above combined with a sensor that measures the velocity of the marine vessel (from which the time of impact of a wave on the planing element or elements can be determined). The active vectoring of thrust can provide a relatively smooth, stable ride of the marine vessel through turbulent water. The signal information from a wave sensor can include wave height information, in which case the control system can actively vector thrust from the propulsive device so as to operate the marine vessel in a "platforming" mode if the wave height is relatively low and in a "contouring" mode if the wave height is relatively high. The buoyant vessel body travels a more uniform height with respect to mean water level in the platforming mode than in the contouring mode

and travels a more uniform height with respect to actual water surface in the contouring mode than in the platforming mode.

According to another aspect of the invention at least one of the attachment mechanisms that transmit lifting forces from the planing element or elements to the buoyant vessel body includes a controllable dynamic force damper. The control system actively adjusts the controllable dynamic force damper in response to signal information from the sensor system to compensate for interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel. The active adjustment of the controllable dynamic force damper can provide a relatively smooth, stable ride of the marine vessel through turbulent water.

According to another aspect of the invention the planing elements have a configuration that permits the marine vessel to ground itself solely on the planing elements. Because the marine vessel can ground itself solely on the planing elements, the buoyant vessel body need not be constructed to withstand grounding contact between the buoyant vessel body itself and solid ground.

According to another aspect of the invention the attachment mechanisms are controllably adjustable to shift the planing element or elements between a high-speed position in which the planing element or elements are displaced in a downward direction relative to the buoyant vessel body during the high-speed travel of the marine vessel, and a docking position in which the planing element or elements are displaced sideways relative to the buoyant vessel body so as to serve as fenders during docking maneuvers of the marine vessel. Because the planing element or elements can serve as docking fenders, the buoyant vessel body need not be constructed to withstand contact with other objects.

Numerous other features, objects, and advantages of the invention will become apparent from the following detailed description when read in connection with the accompanying drawings.

Brief Description of the Drawings

Figs. 1-3 are perspective drawings of a hydroski marine vessel in accordance with the invention.

Fig. 4 is an elevational front view of the vessel of Figs. 1-3, illustrating operating and retracted positions of the hydroskis and operating and retracted positions of the take-off flaps.

Fig. 5 is an elevational side view of the vessel of Figs. 1-3, illustrating the range of available positions of the hydroskis due to active manipulation of the angle of attack of the hydroskis or due to the damping function of oleo struts.

Fig. 6 is a perspective drawing of the vessel of Figs. 1-3 illustrating a ballast tank, ballast intake, and ballast piping.

Fig. 7 is an elevational side view of the vessel of Figs. 1-3 illustrating vertical thrust vectoring of the vessel.

Fig. 8 is a plan view of the vessel of Figs. 1-3 illustrating directional thrust vectoring of the vessel.

Figs. 9 and 10 are perspective drawings of another hydroski marine vessel in accordance with the invention.

Fig. 11 is an elevational side view of the vessel of Figs. 9-10 illustrating internal components of the vessel.

Fig. 12 is a plan view of the vessel of Figs. 9-10 illustrating internal components of the vessel.

Fig. 13 is an elevational side view of the vessel of Figs. 9-10 with the hydroski retracted for buoyant operation of the vessel.

Fig. 14 is an elevational side view of the vessel of Figs. 9-10 with the hydroski and take-off flaps in their operating positions.

Fig. 15 is an elevational side view of the vessel of Figs. 9-10, illustrating variation in the position of the hydroskis due to active manipulation of the angle of attack of the hydroskis or due to the damping function of oleo struts.

Fig. 16 is a set of elevational side views of one of the engines of the vessel of Figs. 9-10 illustrating vertical thrust vectoring of the vessel.

Fig. 17 is a set of plan views of the engines of the vessel of Figs. 9-10 illustrating directional thrust vectoring of the vessel.

Figs. 18 and 19 are perspective drawings of another hydroski marine vessel in accordance with the invention.

Fig. 20 is an elevational side view of the vessel of Figs. 18 and 19.

Fig. 21 is a cross-sectional drawing of a hydroski for use with the vessels of Figs. 1-20, adjusted for a high deadrise angle of the hydroski with respect to the water.

Fig. 22 is a cross-sectional drawing of the hydroski if Fig. 21 adjusted for a lower deadrise angle of the hydroski with respect to the water.

Fig. 23 is a block diagram of a system for active thrust vectoring and active force damping for use with the vessels of Figs. 1-20.

Fig. 24 is a chart of lift to drag ratio L/D of a planing element as a function of the aspect ratio AR of the planing element and the angle of attack α of the planing element.

Fig. 25 is a drag map of coefficient of drag C_d of a marine vessel as a function of $A_p/(\nabla^{2/3})$ and as a function of froude number F_n.

Detailed Description

With reference to Figs. 1-3, marine vessel 10 includes buoyant vessel body 12 and hydroskis 14, upon which buoyant vessel body 12 travels at high speeds of between 158 and 250 knots (200 knots is normal). Engines 16, which may be, for example, Pratt and Whitney 4000 turbofan engines in a thrust class of about 90,000 lbs of thrust per engine, provide propulsive force to buoyant vessel body 12 while hydroskis 14 lift buoyant vessel body 12 upward and such that the buoyant vessel body is out of contact with water. At 200 knots, engines 16 are typically at 50-80% of available thrust. Alternatively, air propellers, ducted fans, turbines, turbofans, or other fluid momentum imparting devices may be used. Hydroskis 14 are non-buoyant and made of titanium or carbon fiber, but in alternative embodiments buoyant hydroskis or hydroskis made of other materials may be used. The dynamic lift from the hydroskis is sufficient to maintain the whole vessel in operating trim with the hydroskis planing on the surface of the water and cutting through waves.

Buoyant vessel body 12 is 410 feet long and has a fully-loaded weight of about 10,000-15,000 tons. Hydroskis 14 have a total length of 301.12 feet and a breadth of 4.76 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroskis is 0.0158 ("aspect ratio" as used herein refers to the breadth of a planing element divided by its length, regardless of whether the total length is wetted). As is illustrated in Fig. 24, taken from an article by Kerwin, Mandel, and Lewis (M.I.T.), Journal of Ship Research, 1972, the lift to drag ratio L/D of the hydroskis is relatively high when

the aspect ratio AR is low and the angle of attack α of the hydroskis (the longitudinal trim angle of the hydroskis relative to the water) is low (all points on this graph less than an aspect ratio of 0.25 are interpolated). In general, the length of the skis should be about 72-80% of the length of the boat and the skis should have a depth of about 8-12% of the length of the boat.

The planing element area A_p of each of the hydroskis is 1433 square feet ("planing element area" as used herein refers to the total length of a planing element multiplied by its breadth, regardless of whether the total length is wetted). Because the planing element area is relatively small compared to the dimensions of the vessel, the ratio of the planing element area to the volumetric equivalent of the weight supported by each planing element (one-half the total weight of the vessel) raised to the power of two-thirds [$A_p/(\nabla^{2/3})$] is less than 1. Fig. 25 shows the coefficient of drag C_d of a marine vessel as a function of $A_p/(\nabla^{2/3})$ and froude number F_n [speed/(gravitational acceleration x hull length)$^{1/2}$]. Reference number 300 on the drag map represents the vessel of Figs. 1-8 loaded to 15,000 tons and travelling at 165 knots. It can be seen that the coefficient of drag C_d is relatively low when $A_p/(\nabla^{2/3})$ is less than 1 and at froude numbers at which such a vessel would be expected to operate. More preferably, $A_p/(\nabla^{2/3})$ is less than 0.9, and even more preferably, less than 0.6. Below is a list of reference numbers on the drag map of Fig. 25 and the items they represent:

300: vessel of Figs. 1-8 at 15 kT and 165 kts;

302: 6,000 lb. Unlimited Hydroplane at 200 kts (temporary condition only on the order of a few seconds);

304: 180 lb. waterskier at 35 kts;

306: 60 kT Great Lakes Ore Carrier at 25 kts;

308: 9 kT Destroyer at 35 kts;
310: Torpedo 3 Human-Powered Sub at 6 kts;
312: 800 kT Supertanker at 25 kts;
314: IACC Yacht at 10 kts;
316: ADCAP Torpedo at 55 kts;
318: Mk50 Adv. Light Torpedo at 50 kts;
320: Clements & Blount Planning Boat.

Due to the minimization of hydrodynamic drag on the marine vessel, at most points in the high-speed operating range aerodynamic drag is substantially greater than hydrodynamic drag.

Referring to Fig. 4, during low-speed operation of the marine vessel hydroskis 14 are positioned as shown in dashed lines in order to reduce draft for entry into areas of water too shallow for the marine vessel to enter with the hydroskis in the operating position, in order to reduce drag while the marine vessel is travelling at buoyant or displacement speeds, and in order for the hydroskis to serve as "fenders" during docking maneuvers. During high-speed operation the hydroskis are positioned as shown in solid lines. The static water line during low-speed operation is represented by horizontal line 18, and the running water line during high-speed operation is represented by horizontal line 20. Hydroskis 14 may also be positioned in an intermediate position to permit grounding of the marine vessel on the hydroskis alone. The bottom of the buoyant vessel body can consequently have a relatively light construction.

In preparation for "take-off" of the marine vessel the hydroskis are moved to the high-speed position, and take-off flaps 22 are deployed in the operating position shown in solid lines in Fig. 4 (the flaps are also shown in the operating position in Fig. 2). The vessel accelerates at a pitch of about 6 degrees (with the skis pitched at 1.8 degrees relative to the vessel) in order

to maximize the lift coefficient. At about 40 or 45 knots the buoyant vessel body is lifted entirely out of contact with the water. As the vessel accelerates between 50 and 135 knots, the take-off flaps are slowly retracted to the position shown in dashed lines in Fig. 4, and the vessel slowly pitches down from 6 degrees to 0 degrees. The take-off flaps provide additional lift necessary to push the buoyant vessel body up and out of contact with the water below 135 knots.

With reference to Fig. 5, hydroskis 14 are attached to buoyant vessel body 12 by pivot 24 and oleo struts 26, which may be 2,000-ton rams, 45 feet in length and 8 feet in diameter, that use hydraulic oil, air, or rheologic fluid as a damping medium for the absorption or reduction of vibrations and shock loadings associated with acoustical noise, impact loadings or wave loadings or any other loadings on hydroskis 14. The dashed lines represent the range of positions of the longitudinal trim angle or angle of attack of hydroskis 14. This angle of attack can be adjusted in order to control the lift provided by the hydroskis, which is equal to $\frac{1}{2}\rho v^2 A_W (dC_L/d\alpha)\alpha(\cos\beta)$, where ρ is the density of water, v is velocity of the marine vessel, A_W is the wetted area of the planing element at a given point in time, C_L is coefficient of lift, and β is the deadrise (or dihedral) angle of the hydroskis. Also, oleo struts 26 can be dynamically controlled in order to compensate for unwanted forces experienced by the marine vessel due to interactions of the vessel with waves. Other hydraulic, electric or mechanical devices may be substituted for oleo struts 26. The oleo struts are also used to move the hydroskis between the high-speed position (solid lines in Fig. 4), the low-speed position (dashed lines in Fig. 4), and the intermediate "grounding" position.

Fig. 6 shows a ballast tank 28 in buoyant vessel body 12, and a ballast intake valve 30 is provided on one of hydroskis 14 to enable ballast tank 28 to be filled with water through ballast piping in oleo strut 26. Ballast tank 28 is actually one of a number of such ballast tanks within the buoyant vessel body, and ballast intake valve 30 is one of a number of such ballast intake valves on both hydroskis 14. As fuel is consumed by the marine vessel, ballast intake can be controlled by controlling the ballast intake valves so as to compensate for the lost weight with intake of water into the ballast tanks. This prevents undue lifting of the buoyant vessel body due to planing, which would result in inefficient operation of the marine vessel due to a decrease in the length of the water line and a corresponding increase in drag. A 10,000 ton boat might burn about 1,500 tons of fuel during a typical voyage.

With reference to Figs. 7 and 8, steering of the marine vessel can be accomplished through thrust vectoring of engines 16. The engines include rotatable divergent/convergent nozzles 32 in the exhaust plenum that can be adjusted to vector thrust upward up to about 20°, downward up to about 20°, or in a neutral position. Similarly, engines 16 also include rotatable vanes 34 in the exhaust plenum that can be adjusted to vector thrust to port up to about 20°, to starboard up to about 20°, or in a neutral position. In alternative embodiments the thrust provided by an engine or propulsive device can be vectored by other variable-geometry vanes, paddles, nozzles or other fluid momentum vectoring devices situated in the thrust stream and capable of being rotated about the desired axis to direct the thrust stream in a direction appropriate to the intended vectoring. In one such design a cone of interleaved petals is provided that can be directed up to about 20°

off of center in any given direction, the cone having a nozzle whose size can be varied by appropriate adjustment of the petals. Thrust vectoring can alternatively be accomplished by physical movement or rotation of the propulsive device itself.

Referring to Figs. 21 and 22, each hydroski 14 includes surface elements 36 and 38 pivotally connected about pivot 40. Rams 42, which may be hydraulic, air, or rheologic fluid-damped struts, are connected between surface elements 36 and 38 and a central vertical strut 44. Rams 42 can be adjusted to vary the deadrise angle β of hydroski 14 between a high value of 60 degrees or higher with respect to horizontal and a low value of 0 degrees with respect to horizontal and anywhere in-between. Figs 21 and 22 show two different configurations of the hydroski corresponding to two different deadrise angles. As is discussed above the lift provided by the hydroskis is proportional to the cosine of the deadrise angle β of the hydroskis, and thus lift can be controlled by controlling the deadrise angle through rams 42. At takeoff, the deadrise angle should be at 0 degrees, and at very high speed the deadrise angle should be high. Other hydraulic, electric or mechanical devices may be substituted for rams 42. The deadrise adjustment feature is the primary mechanism of compensation for overspeed or underspeed, which can result from interactions between the vessel and waves, aerodynamic forces, or decelerations due to maneuvering of the vessel, because this feature makes it possible to very easily relax or increase lift from the hydroskis. This ensures that the waterline length on the hydroskis stays at the correct value, and thus the center of lift of the vessel does not move backward or forward.

With reference to Fig. 23, the marine vessel is fitted with forward-looking wave sensor 46, backward-

looking wave sensor 48, velocity sensor 49, accelerometers 50, and fuel gauge 52, all of which transmit signal information to control computer 54. Based on this signal information the control computer actively controls nozzles 32 and vanes 34 of the engines, oleo struts 26 and rams 42, ballast intake valves 30, and aerodynamic controls 55 (including ailerons for roll control, elevons for pitch control, and speed brakes for speed reduction). Wave sensors 46 and 48 may include RADAR or millimeter-wave RADAR or LIDAR technology for determining the height, distance, and velocity of waves. Accelerometers 50 may be laser accelerometers.

In particular, in response to undesired accelerations of the marine vessel sensed by accelerometers 50 due to interactions between the vessel and waves, or in response to predicted impacts of waves on the hydroskis based on information provided by wave sensor 46 combined with vessel velocity as measured by velocity sensor 49, control computer 54 actively vectors thrust from the engines in an appropriate direction and amount so as to compensate for undesired movement of the vessel. The undesired acceleration may result in pitch (rotation about a transverse axis), yaw (rotation about a vertical axis), roll (rotation about a longitudinal axis), or change in velocity, or any combination thereof. In addition, control computer 54 can adjust aerodynamic controls 55 in response to undesired motion of the vessel.

The control computer 54 also, in response to undesired accelerations of the marine vessel sensed by accelerometers 50 (pitch, yaw, roll, change in velocity), or in response to predicted impacts of waves on the hydroskis based on information provided by wave sensor 46 combined with vessel velocity as measured by velocity sensor 49, actively adjusts oleo struts 26 and the

response rate of these struts so as to actively damp or reduce impact loadings and wave loadings, including wave impact loadings. Oleo struts 26 also inherently damp or reduce vibrations and loadings wholly apart from computer control. Immediately prior to a wave hit on one of the hydroskis, control computer 54 creates a differential pulse or force in one or more of oleo struts 26 in a direction opposite to the anticipated pulse created by the wave hit. Once the wave has hit the hydroski, control computer 54 softens residual forces in oleo struts 26, measured by accelerometers 50, in a similar manner. If the residual forces are directed upward, oleo struts 26 are caused to pull the hydroski upward; if the residual forces are directed downward, the oleo struts are caused to pull the hydroski downward.

Control computer 54 also adjusts oleo struts 26 to vary the angle of attack of the hydroskis and adjusts rams 42 to vary the deadrise angle of the hydroskis in order to provide a lift that is appropriate for a given speed of the marine vessel as measured by velocity meter 49. Thus, the hydroskis are capable of maintaining appropriate lift in a planing condition over a broad range of speeds. This is important because if the lift is too high the waterline length will decrease and consequently drag will increase.

During normal operation the marine vessel operates in a platforming mode of operation in which the buoyant vessel body travels at a constant height with respect to the mean water level. This is possible because thrust vectoring can overcome any pitching forces at a given speed where the wave height does not exceed the difference between flat water normal running trim and the bottom of the buoyant vessel body (i.e., where the waves will not crash into the buoyant vessel body). Thus, the

buoyant vessel body need not be constructed to withstand high-speed impacts from waves.

Furthermore, if the wave height detected by wave sensor 46 is such that the wave crests would be close to five feet from the bottom of the buoyant vessel body (in the case of a 410-foot vessel), or if an adverse weather report is received, then control computer 54 can shift from the standard platforming mode of operation to a contouring mode of operation, in which the buoyant vessel body travels at a constant height with respect to the actual water surface (or at least a more constant height with respect to the actual water surface than in the platforming mode), in order to prevent impact between the waves and the buoyant vessel body. Depending on the height of the waves, the control computer 54 may operate in an intermediate mode of operation in which contouring occurs only to the extent necessary to keep the crests of the waves more than five feet below the bottom of the buoyant vessel body. In other words, the skis go through the waves in this intermediate mode, but the marine vessel is actively pitched up and down by active thrust vectoring sufficiently to ensure that the bottom of the buoyant vessel body will never impact a wave. The contouring is accomplished by active thrust vectoring of engines 16. Also, during the contouring or intermediate mode of operation, control computer 54 causes the marine vessel to travel at an angle with respect to the waves. In particular, if the marine vessel is unable or might be unable to travel over a particular large wave having a height greater than a threshold value, the control computer causes the marine vessel to make a sharp pitching turn. The severity of the turn is proportional to the greater of two limiting factors: 1) the amount of time remaining before the particular large wave could impact the vessel, or 2) the size of the large wave,

which determines the amount of work required and hence the amount of time required, once the wave has reached the vessel, for the vessel to execute a contouring maneuver (contouring over the large wave) such that the buoyant vessel body does not impact the wave. The contouring and intermediate modes of operation are essentially emergency modes.

Control computer 54 can maintain a constant vessel weight by causing water to be introduced into the ballast tanks through ballast intake valves 30 in response to information received from fuel gauge 52 concerning fuel consumption. The maintenance of a constant vessel weight and a constant lift ensures a near constant waterline length of the marine vessel throughout the speed range of high-speed operation, which in turn minimizes drag.

During grounding of the marine vessel on the hydroskis, the control computer controls oleo struts 26 in response to information received from accelerometers 50 and forward-looking and backward-looking wave sensors 46 and 48, in order to compensate for undesired forces due to interaction between the marine vessel and waves. If a wave hit on the port side of the vessel is imminent, the oleo struts on the starboard side are stiffened and then relaxed slowly so as to absorb energy and to allow the vessel to shift gently toward the starboard side. Likewise, if a wave hit on the starboard side of the vessel is imminent, the oleo struts on the port side are stiffened and then relaxed slowly so as to absorb energy and to allow the vessel to shift gently toward the port side.

With reference to Figs. 9-12, another embodiment of a marine vessel 110 operates in the same manner as marine vessel 10 of Figs. 1-8 except as otherwise indicated below. The marine vessel includes buoyant vessel body 112 and a single hydroski 114, upon which

buoyant vessel body 112 travels at high speeds in the range of 300 knots. Engines 116 are in a thrust class of about 750 lbs of thrust per engine.

Buoyant vessel body 112 is 34 feet long and has a fully-loaded weight of about 6.26 tons. Hydroski 114 has a length of 24.97 feet and a breadth of 0.76 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroski is 0.03. The planing element area A_p of the hydroski is 18.98 square feet. Reference number 302 on the drag map of Fig. 25 represents the vessel of Figs. 9-17 loaded to 10,000 tons and travelling at 200 knots.

During low-speed operation of the marine vessel hydroski 114 is positioned as shown in Fig. 13. During high-speed operation the hydroski is positioned as shown in Fig. 14. The static water line during low-speed operation is represented by horizontal line 118, and the running water line during high-speed operation is represented by horizontal line 120.

In preparation for "take-off" of the marine vessel the hydroski is moved to the high-speed position, and take-off flaps 122, which are mounted on the wings of the vessel, are deployed in the operating position shown in solid lines in Fig. 14. As the vessel accelerates between 5 and 50 knots, the take-off flaps are slowly retracted to the position shown in dashed lines in Fig. 13. Take-off flaps 122 assist in stability during "take-off" and "landing" of the single-hydroski marine vessel.

Because the marine vessel has a single hydroski 114 it is highly maneuverable and capable of relatively sharp cornering. As thrust vectoring or aerodynamic controls or both cause the marine vessel to turn, the lift forces provided by the hydroski pushes the vessel into the turn in a banking maneuver.

With reference to Fig. 15, hydroski 114 is attached to buoyant vessel body 112 by pivot 124 and oleo

struts 126. Solid and dashed lines represent the range of positions of the longitudinal trim angle or angle of attack of hydroski 114.

With reference to Figs. 16 and 17, engines 116 include rotatable nozzles 132 that can be adjusted to vector thrust upward, downward, or in a neutral position. Similarly, engines 116 also include rotatable vanes 134 that can be adjusted to vector thrust to port, to starboard, or in a neutral position.

Referring to Figs. 18-20, another embodiment of a marine vessel 210 operates in the same manner as marine vessel 10 of Figs. 1-8 except as otherwise indicated below. The marine vessel includes buoyant vessel body 212 and a hydroskis 214, upon which buoyant vessel body 212 travels at high speeds of between 125 and 250 knots. Engines 216 are in a thrust class of about 90,000 lbs of thrust per engine.

Buoyant vessel body 212 is 300 feet long and has a fully-loaded weight of about 1,800 tons. Hydroskis 214 have a length of 220.3 feet and a breadth of 2.14 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroskis is 0.097. The planing element area A_p of the hydroskis is 942.88 square feet. Reference number 304 on the drag map of Fig. 25 represents the vessel of Figs. 18-20 loaded to 1,500 tons and travelling at 165 knots.

There have been described novel and improved apparatus and techniques for marine vessel hydroskiing. It is evident that those skilled in the art may now make numerous uses and modifications of and departures from the specific embodiments described herein without departing from the inventive concept. For example, it is possible to construct other marine vessels according to the invention having different dimensions and performance parameters, e.g., vessels with more powerful engines that

travel at substantially greater speeds than those described herein.

What is claimed is:

1. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed; and

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water throughout prolonged high-speed travel of the marine vessel by virtue of lifting action due to planing;

the planing element having a length and breadth that, when multiplied, define a planing element area;

the planing element supporting a weight that, when divided by mass density of water, defines a volumetric equivalent of the weight supported by the planing element;

the ratio of the planing element area to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds being less than 1.

2. The marine vessel of claim 1 wherein the ratio of the planing element area to the volumetric equivalent of the total weight of the marine vessel raised to the power of two-thirds is less than 0.9.

3. The marine vessel of claim 2 wherein the ratio of the planing element area to the volumetric equivalent of the total weight of the marine vessel raised to the power of two-thirds is less than 0.6.

4. The marine vessel of claim 1 wherein

there are a plurality of planing elements attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during

high-speed travel of the marine vessel, by virtue of lifting action due to planing;

each planing element has a length and breadth that, when multiplied, defines a planing element area;

each planing element supports a weight that, when divided by mass density of water, defines a volumetric equivalent of the weight supported by the planing element;

the weight supported by each planing element is a portion of total weight supported by the plurality of planing elements; and

the ratio of the planing element area of each of the planing elements to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds is less than 1 throughout prolonged high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with water.

5. The marine vessel of claim 1 wherein the propulsive device is attached directly to the buoyant vessel body.

6. The marine vessel of claim 1 wherein the high speed is greater than 100 knots.

7. The marine vessel of claim 6 wherein the high speed is greater than 150 knots.

8. The marine vessel of claim 1 wherein the prolonged high-speed travel has a duration on the order of one or more hours.

9. The marine vessel of claim 1 wherein the at least one planing element is buoyant.

10. The marine vessel of claim 1 wherein the at least one planing element is non-buoyant.

11. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed; and

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;

the planing element having a length and a breadth such that the length of the planing element is at least 20 times the breadth of the planing element.

12. The marine vessel of claim 11 wherein the length of the planing element is at least 40 times the breadth of the planing element.

13. The marine vessel of claim 12 wherein the length of the planing element is at least 100 times the breadth of the planing element.

14. The marine vessel of claim 11 wherein

there are a plurality of planing elements attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and

each planing element has a length and a breadth such that the length of the planing element is at least 20 times the breadth of the planing element.

15. The marine vessel of claim 11 wherein the propulsive device is attached directly to the buoyant vessel body.

16. The marine vessel of claim 11 wherein the high speed is greater than 100 knots.

17. The marine vessel of claim 16 wherein the high speed is greater than 150 knots.

18. The marine vessel of claim 11 wherein the prolonged high-speed travel has a duration on the order of one or more hours.

19. The marine vessel of claim 11 wherein the at least one planing element is buoyant.

20. The marine vessel of claim 11 wherein the at least one planing element is non-buoyant.

21. A hydroski assembly comprising:

a hydroski defining a planing surface to lift a buoyant vessel body of a marine vessel upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and

a plurality of attachment mechanisms attached to the hydroski and constructed for attachment to the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the hydroski to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

at least one of the attachment mechanisms being controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant vessel

body is lifted upward and out of contact with the water, so as to adjust an angle of attack of the hydroski with respect to the water during the high-speed travel.

22. The hydroski assembly of claim 21 wherein the attachment mechanism that is controllably adjustable in length comprises a strut.

23. The hydroski assembly of claim 22 wherein the strut is an oleo strut that is controllably adjustable in length.

24. The hydroski assembly of claim 21 wherein one of the attachment mechanisms other than the attachment mechanism that is controllably adjustable in length comprises a pivot mechanism constructed for direct attachment of the hydroski to the buoyant vessel body through the pivot mechanism.

25. The hydroski assembly of claim 21 wherein the hydroski is buoyant.

26. The hydroski assembly of claim 21 wherein the hydroski is non-buoyant.

27. A hydroski assembly comprising:

a hydroski defining a planing surface to lift a buoyant vessel body of a marine vessel upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and

a deadrise angle adjustment mechanism attached to the hydroski and constructed to controllably adjust a deadrise angle of the hydroski with respect to the water during the high-speed travel of the marine vessel in

which the buoyant vessel body is lifted upward and out of contact with the water.

28. The hydroski assembly of claim 27 wherein:

the hydroski comprises a plurality of surface elements extending the length of the hydroski, the plurality of surface elements being pivotally attached to each other along the length of the hydroski about at least one pivot; and

the deadrise angle adjustment mechanism comprises a plurality of struts, attached to the surface elements of the hydroski, that are controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with the water, so as to adjust an angle between the surface elements about the pivot to vary a deadrise angle of the hydroski with respect to the water during the high-speed travel.

29. The hydroski assembly of claim 27 wherein the hydroski is buoyant.

30. The hydroski assembly of claim 27 wherein the hydroski is non-buoyant.

31. The hydroski assembly of claim 27 further comprising a plurality of attachment mechanisms attached to the hydroski and constructed for attachment to the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the hydroski to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water, at least one of the attachment mechanisms being controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant

vessel body is lifted upward and out of contact with the water, so as to adjust an angle of attack of the hydroski with respect to the water during the high-speed travel.

32. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;

at least one ballast tank within the buoyant vessel body;

at least one ballast intake valve; and

ballast piping connecting the ballast tank with the ballast intake valve;

the ballast intake valve being arranged to controllably receive water during high-speed travel of the marine vessel to fill the ballast tank through the ballast piping.

33. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;

a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves;

a control system connected to the sensor system and to the propulsive device and configured to actively vector thrust from the propulsive device in response to the signal information from the sensor system to compensate for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

34. The marine vessel of claim 33 wherein the sensor system comprises at least one accelerometer that directly measures motion of the marine vessel due to waves.

35. The marine vessel of claim 33 wherein the sensor system comprises a wave sensor that detects water waves, and wherein the signal information provided by the sensor system comprises information from which anticipated motion of the marine vessel due to water waves can be predicted.

36. The marine vessel of claim 33 wherein the propulsive device comprises a plurality of independent propulsion units controlled by the control system.

37. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises pitch motion.

38. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises yaw motion.

39. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises roll motion.

40. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises a change in velocity.

41. The marine vessel of claim 33 further comprising a directional control system connected to the propulsive device to actively vector thrust from the propulsive device to steer the marine vessel.

42. The marine vessel of claim 33 wherein the signal information pertaining to interaction between the marine vessel and the water waves comprises wave height information, and wherein the control system is configured to actively vector thrust from the propulsive device so as to operate the marine vessel in a platforming mode if the wave height is relatively low and in a contouring mode if the wave height is relatively high, the buoyant vessel body travelling a more uniform height with respect to mean water level in the platforming mode than in the contouring mode and travelling a more uniform height with respect to actual water surface in the contouring mode than in the platforming mode.

43. The marine vessel of claim 42 wherein the control system is configured to actively vector thrust from the propulsive device so as to operate the marine vessel in an intermediate mode if the wave height is intermediate, the buoyant vessel body, in the intermediate mode, travelling a more uniform height with respect to mean water level than in the contouring mode but a less uniform height with respect to mean water level than in the platforming mode, and travelling a more uniform height with respect to actual water surface than in the platforming mode but a less uniform height with

respect to actual water surface than in the contouring mode.

44. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;

a plurality of attachment mechanisms attached to the planing element and the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the planing element to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

at least one of the attachment mechanisms comprising a controllable dynamic force damper;

a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves;

a control system connected to the sensor system and to the controllable dynamic force damper and configured to actively adjust the controllable dynamic force damper in response to the signal information from the sensor system to compensate for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

45. The marine vessel of claim 44 wherein the controllable dynamic force damper dynamically dampens loadings and vibrations experienced by the planing

element apart from adjustment of the controllable dynamic force damper by the control system.

46. The marine vessel of claim 44 wherein the attachment mechanism that comprises the controllable dynamic force damper comprises a strut.

47. The marine vessel of claim 44 wherein one of the attachment mechanisms other than the attachment mechanism that comprises the controllable dynamic force damper comprises a pivot mechanism constructed for direct attachment of the hydroski to the buoyant vessel body through the pivot mechanism.

48. The marine vessel of claim 44 wherein the high speed is greater than 100 knots.

49. The marine vessel of claim 48 wherein the high speed is greater than 150 knots.

50. The marine vessel of claim 44 wherein the planing element is buoyant.

51. The marine vessel of claim 44 wherein the planing element is non-buoyant.

52. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;

a plurality of planing elements attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action; and

a plurality of attachment mechanisms attached to the planing elements and the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the planing elements to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

the planing elements having a configuration that permits the marine vessel to ground itself solely on the planing elements.

53. The marine vessel of claim 52 wherein the attachment mechanisms are controllably adjustable to shift the planing elements between a high-speed position in which the planing elements are displaced in a downward direction relative to the buoyant vessel body during the high-speed travel of the marine vessel, and a low-draft position in which the planing elements are retracted upwardly so as to reduce draft for entry of the marine vessel into shallow water.

54. The marine vessel of claim 53 wherein the configuration of the planing elements that permits the marine vessel to ground itself solely on the planing elements is the low-draft position.

55. The marine vessel of claim 53 wherein the low-draft position of the planing elements reduces hydrodynamic drag during low-speed operation of the marine vessel in which the buoyant vessel body is in contact with water.

56. The marine vessel of claim 52 wherein at least one of the attachment mechanisms comprises a dynamic force damper.

57. The marine vessel of claim 56 further comprising:

a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves during grounding of the marine vessel;

a control system connected to the sensor system and to the dynamic force damper and configured to adjust the dynamic force damper in response to the signal information from the sensor system to compensate for the interaction between the marine vessel and the water waves during the grounding of the marine vessel.

58. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action; and

a plurality of attachment mechanisms attached to the planing element and the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the planing element to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

the attachment mechanisms being controllably adjustable to shift the planing element between a high-speed position in which the planing element is displaced in a downward direction relative to the buoyant vessel body during the high-speed travel of the marine vessel, and a docking position in which the planing element is displaced sideways relative to the buoyant vessel body so

as to serve as a fender during docking maneuvers of the marine vessel.

59. The marine vessel of claim 58 wherein the at least one planing element comprises a plurality of planing elements.

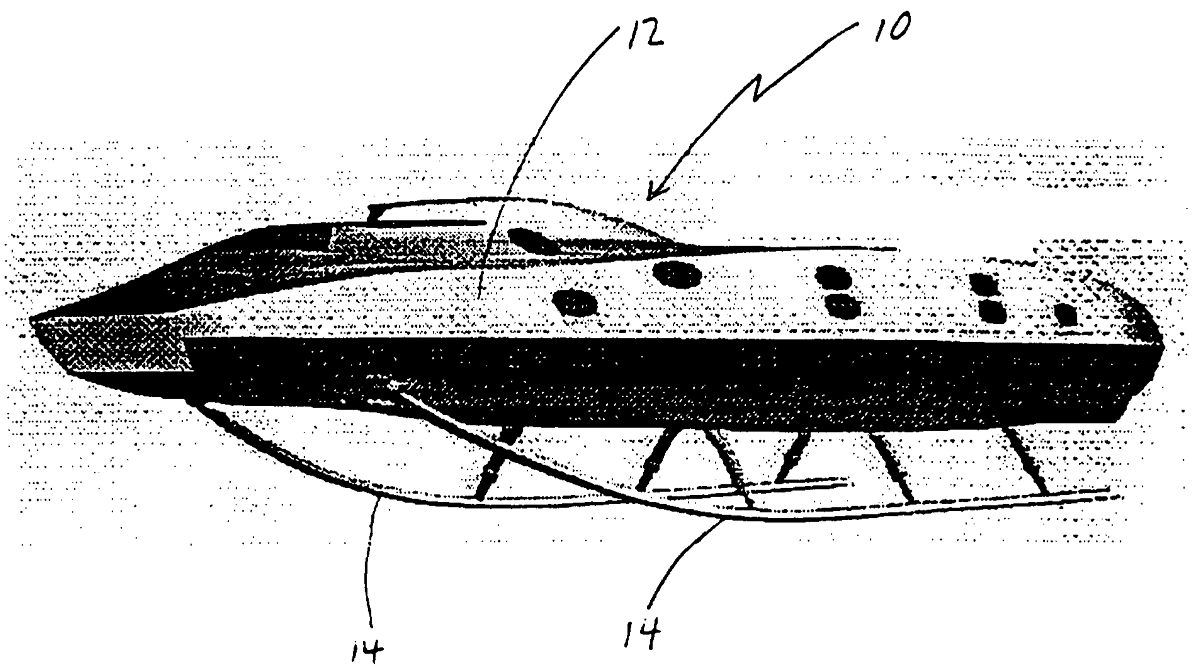


Fig.1

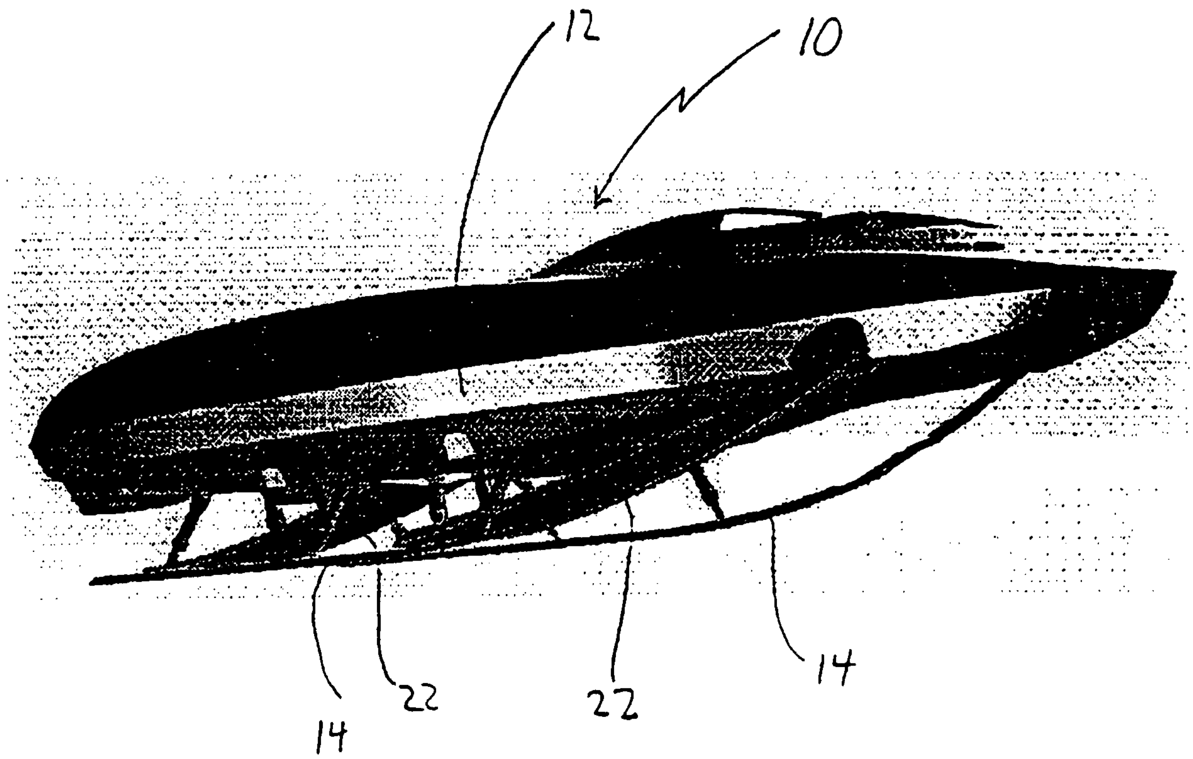


Fig.2

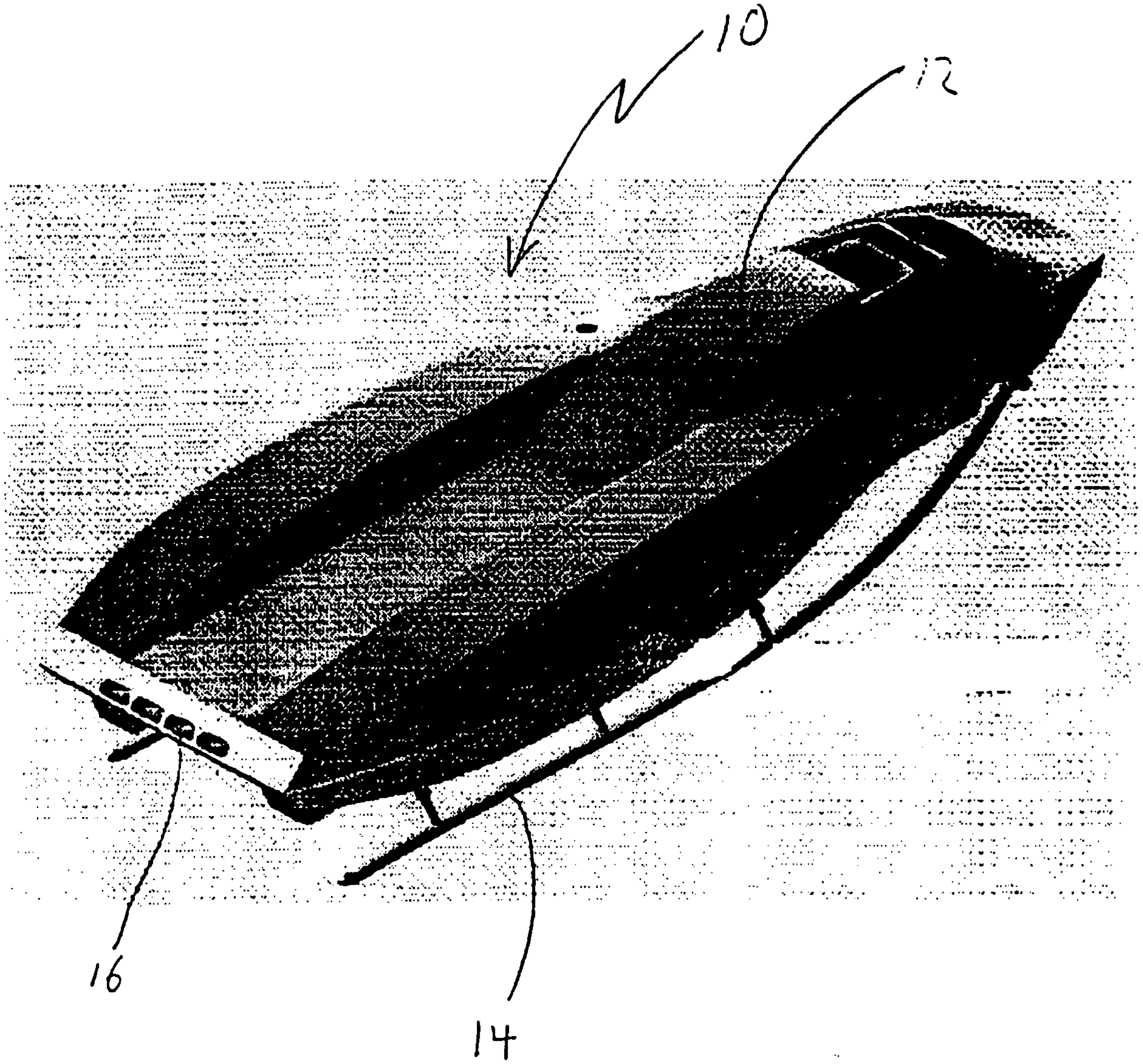
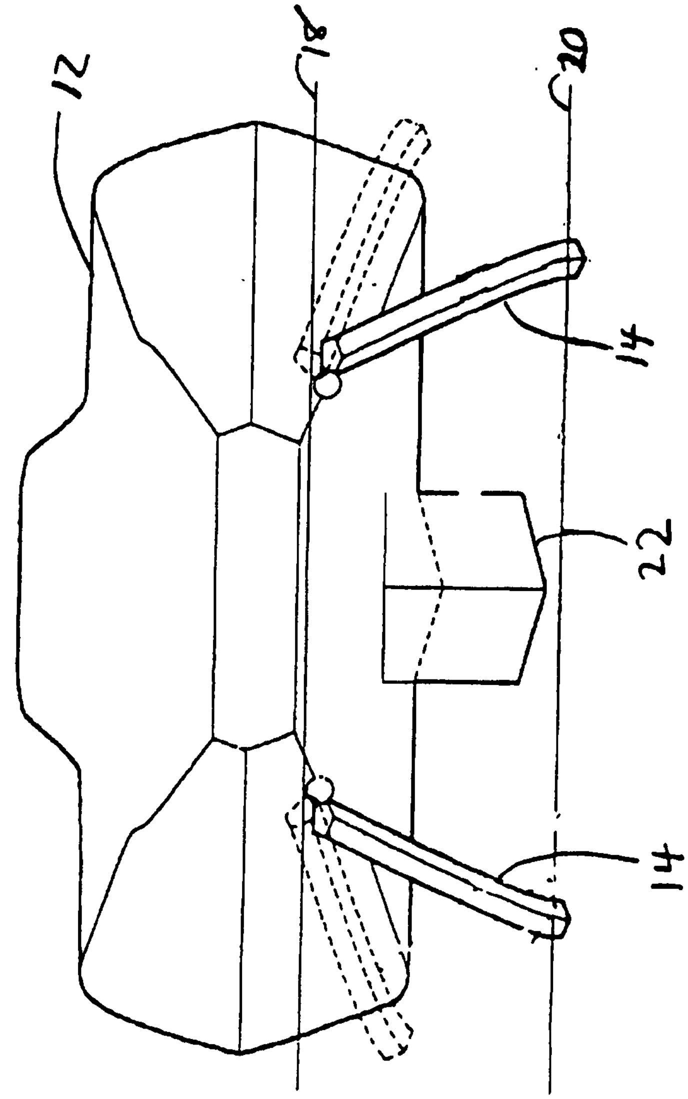


Fig.3

Fig.4



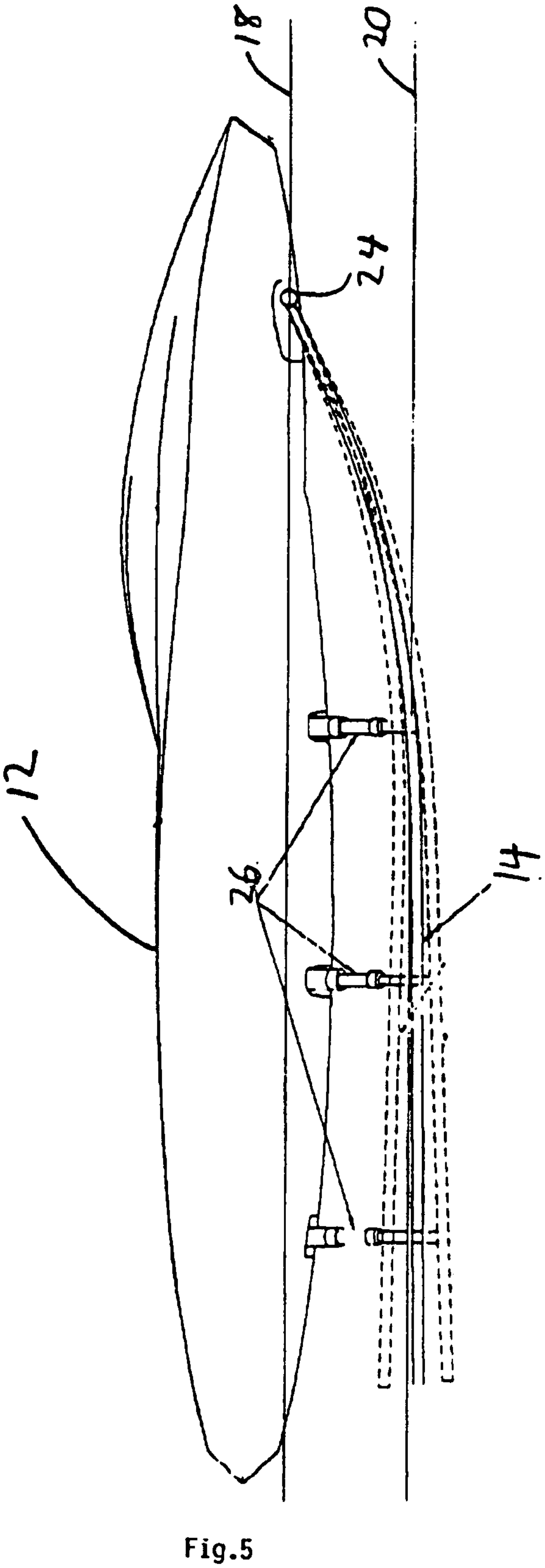


Fig.5

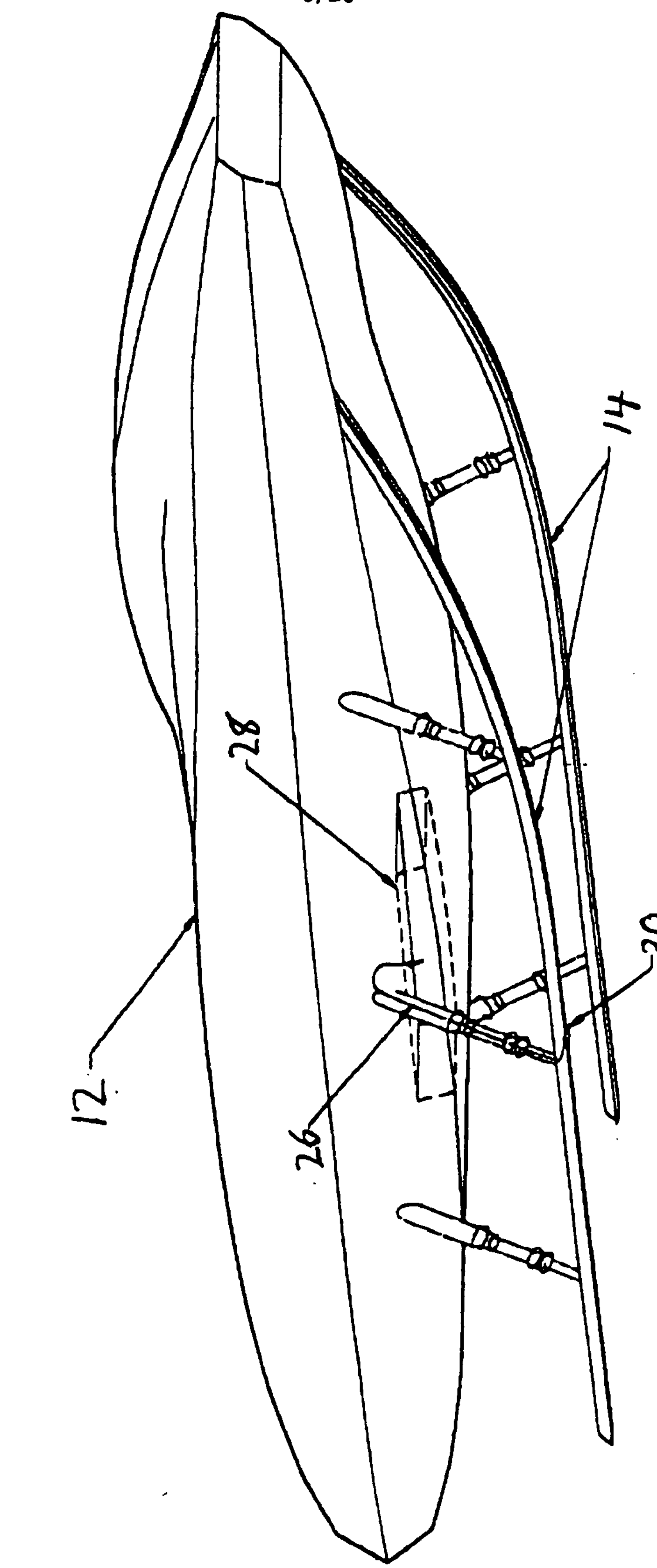


Fig.6

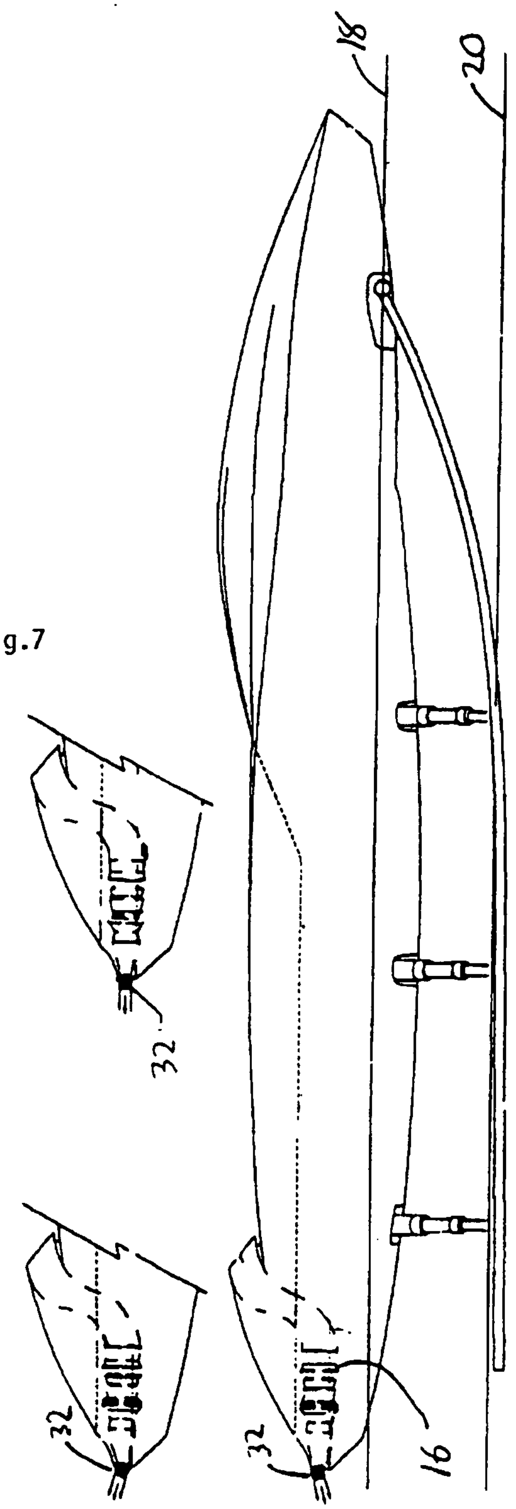


Fig.7

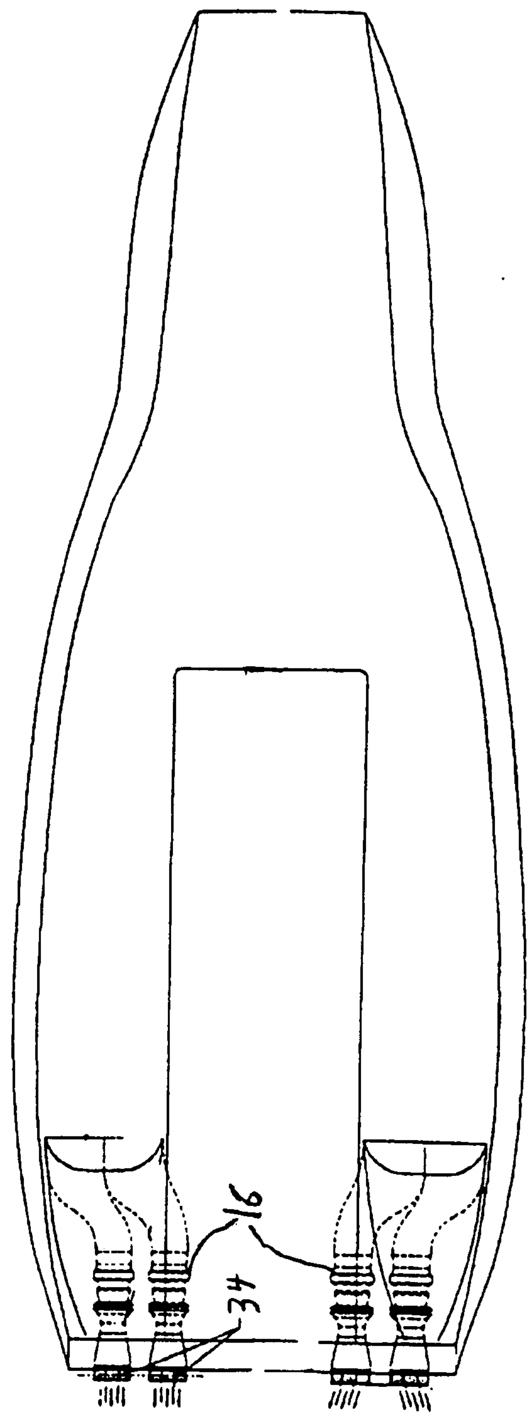


Fig.8

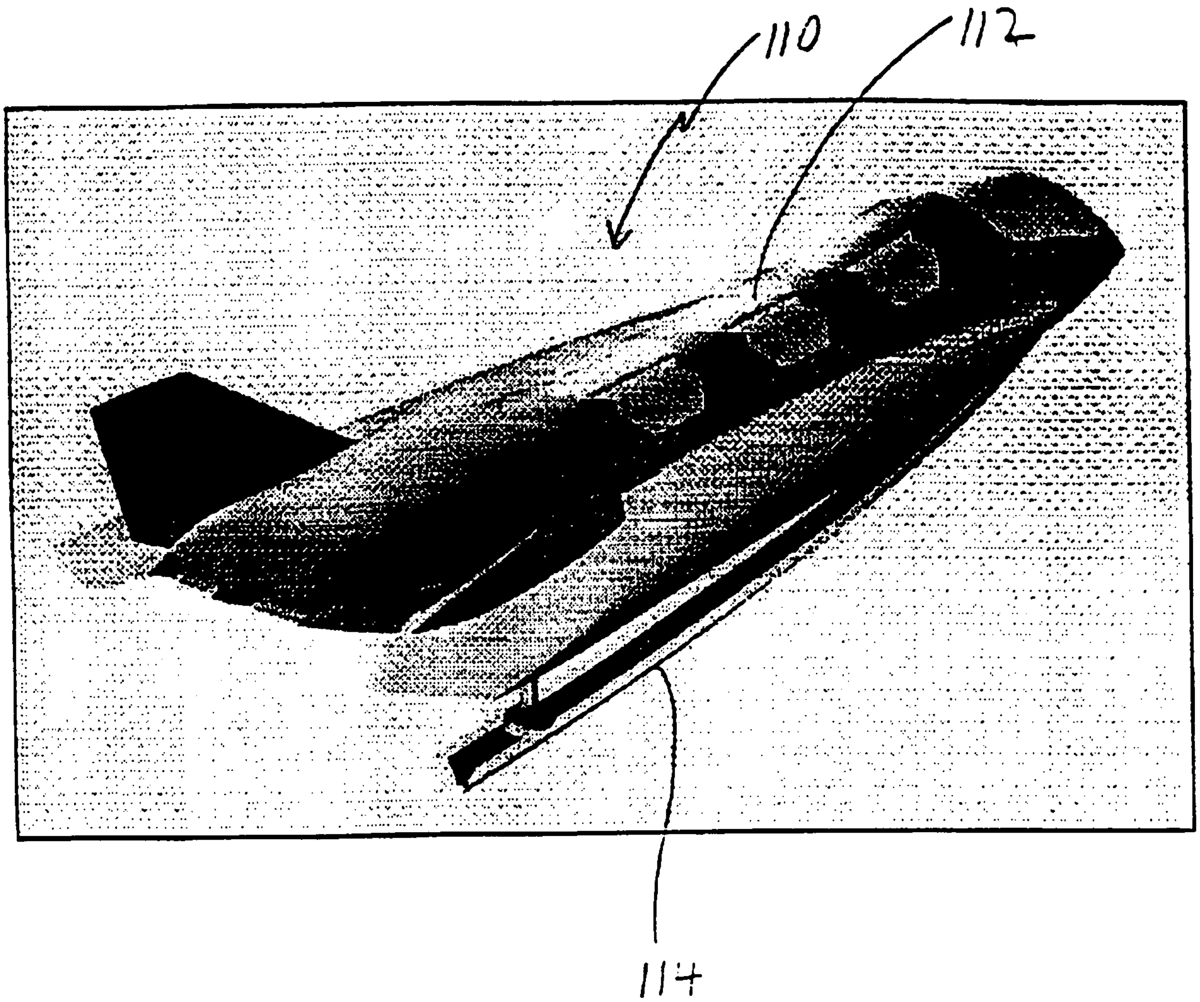


Fig.9

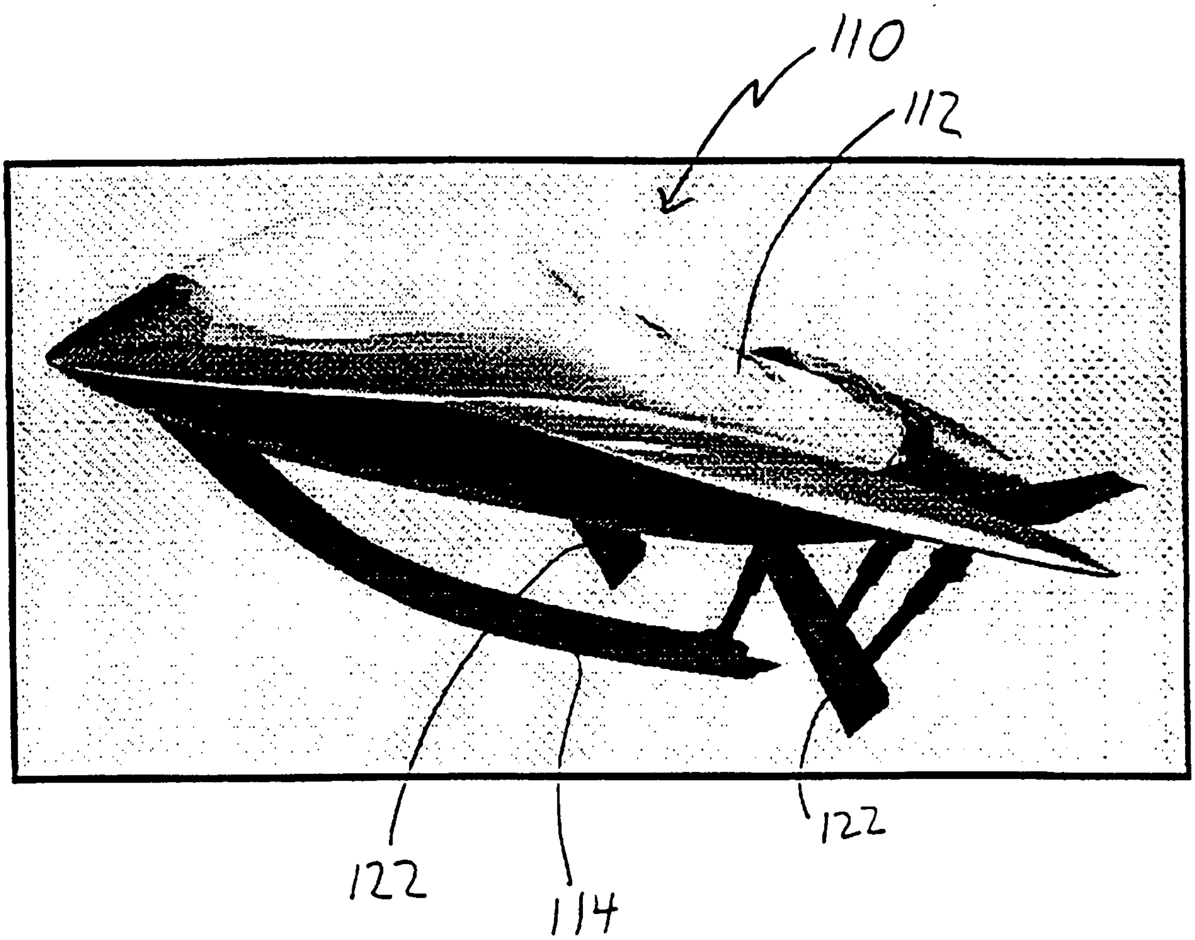


Fig.10

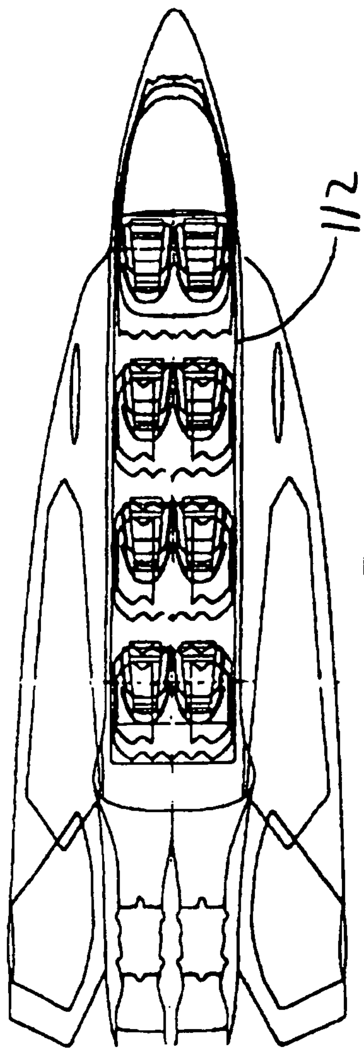


Fig.11

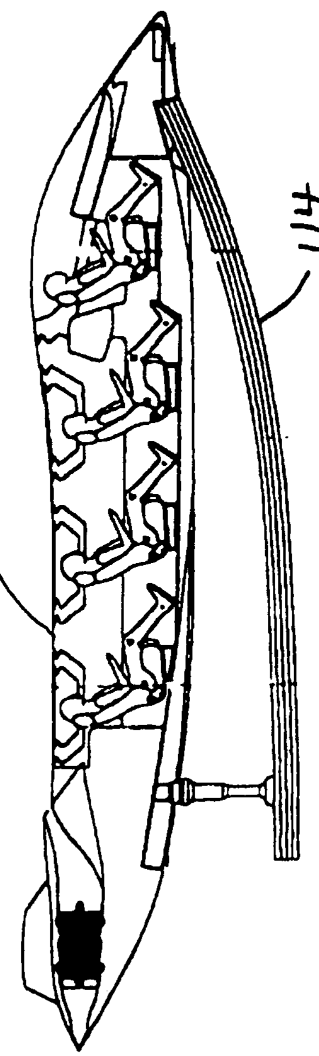


Fig.12

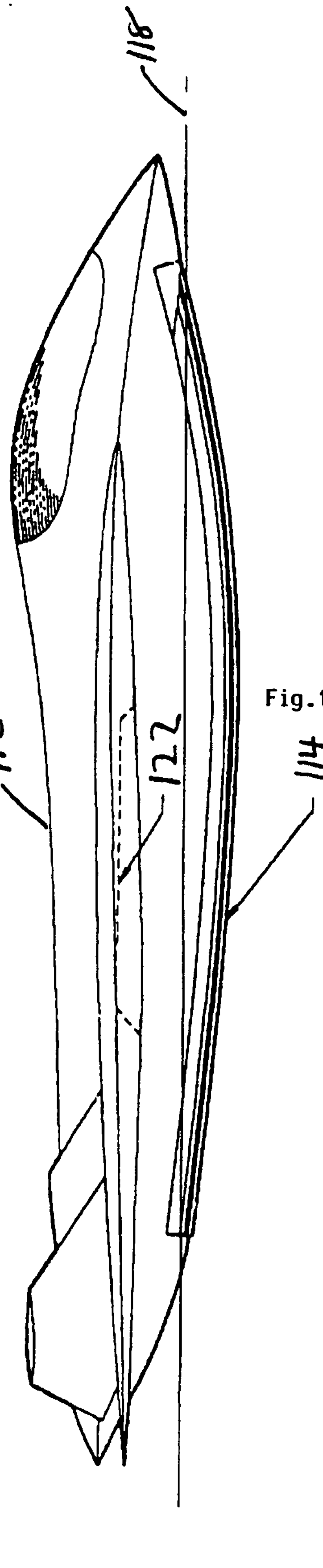


Fig.13

Fig.14

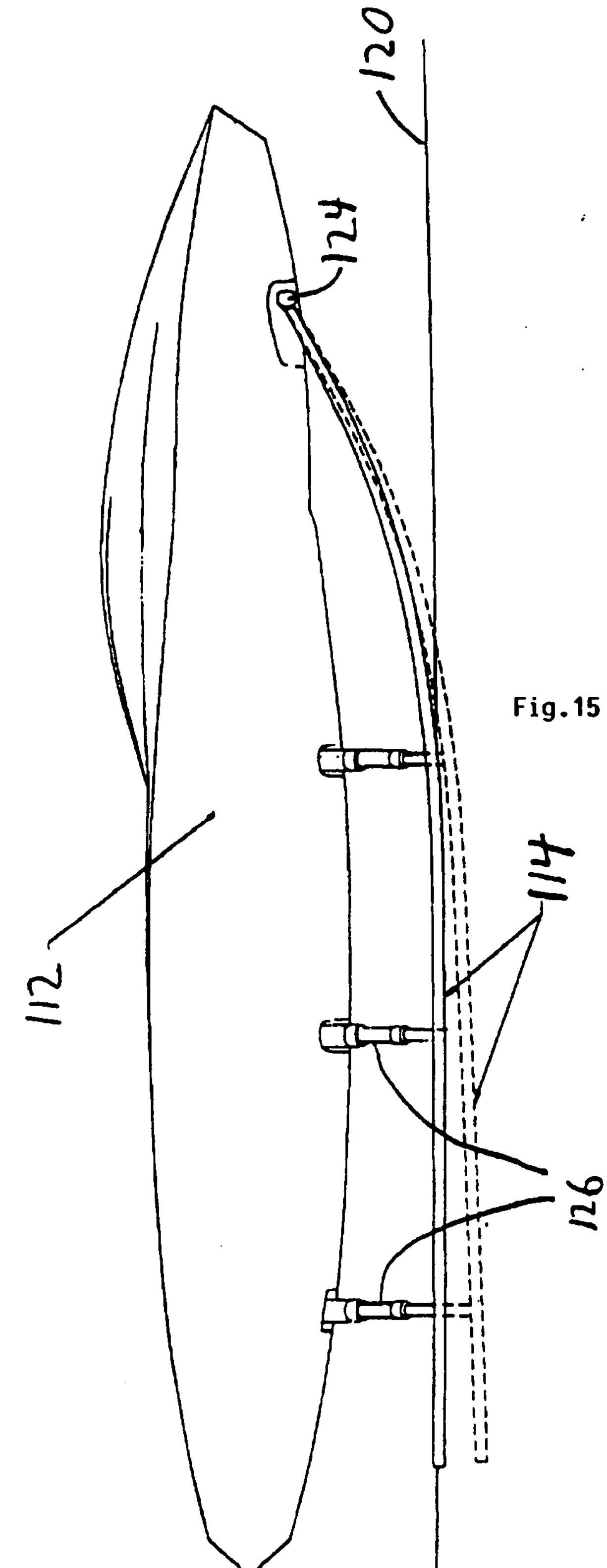


Fig.15

Fig.17

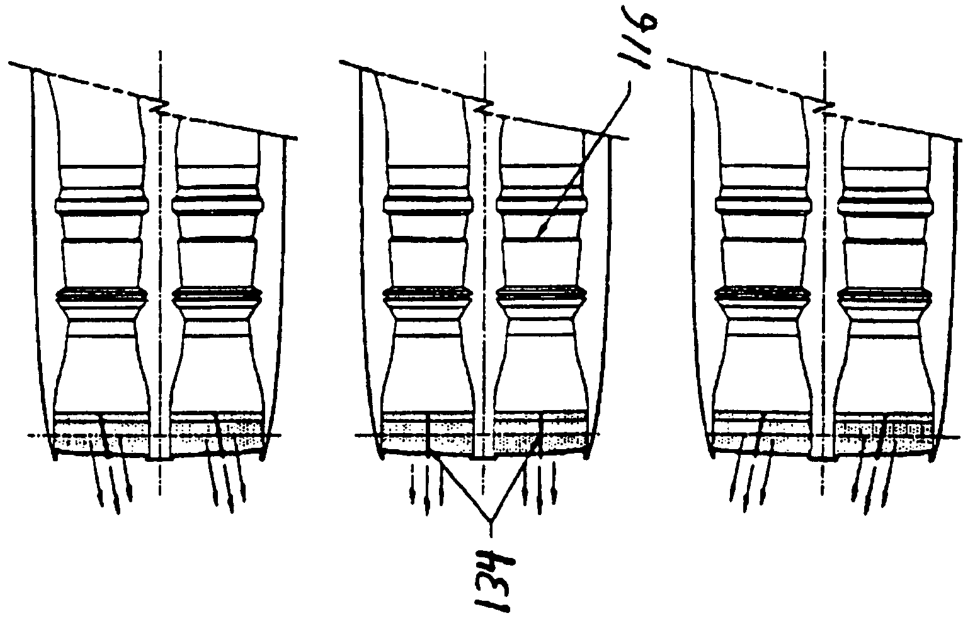
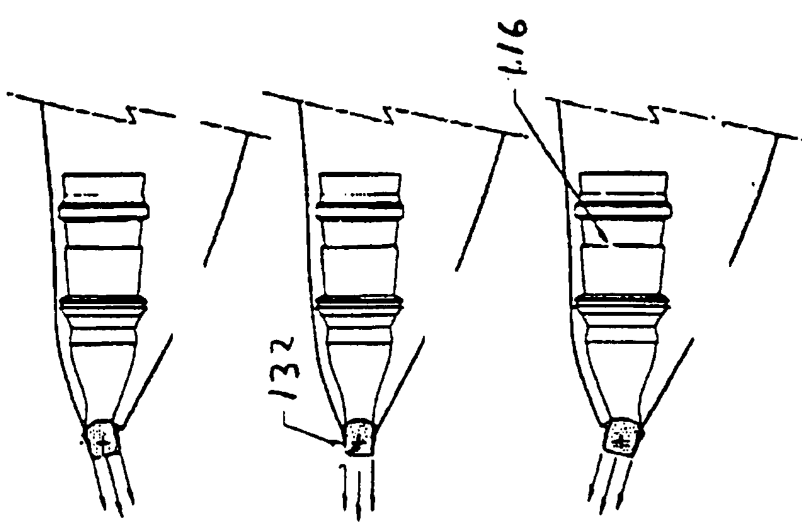


Fig.16



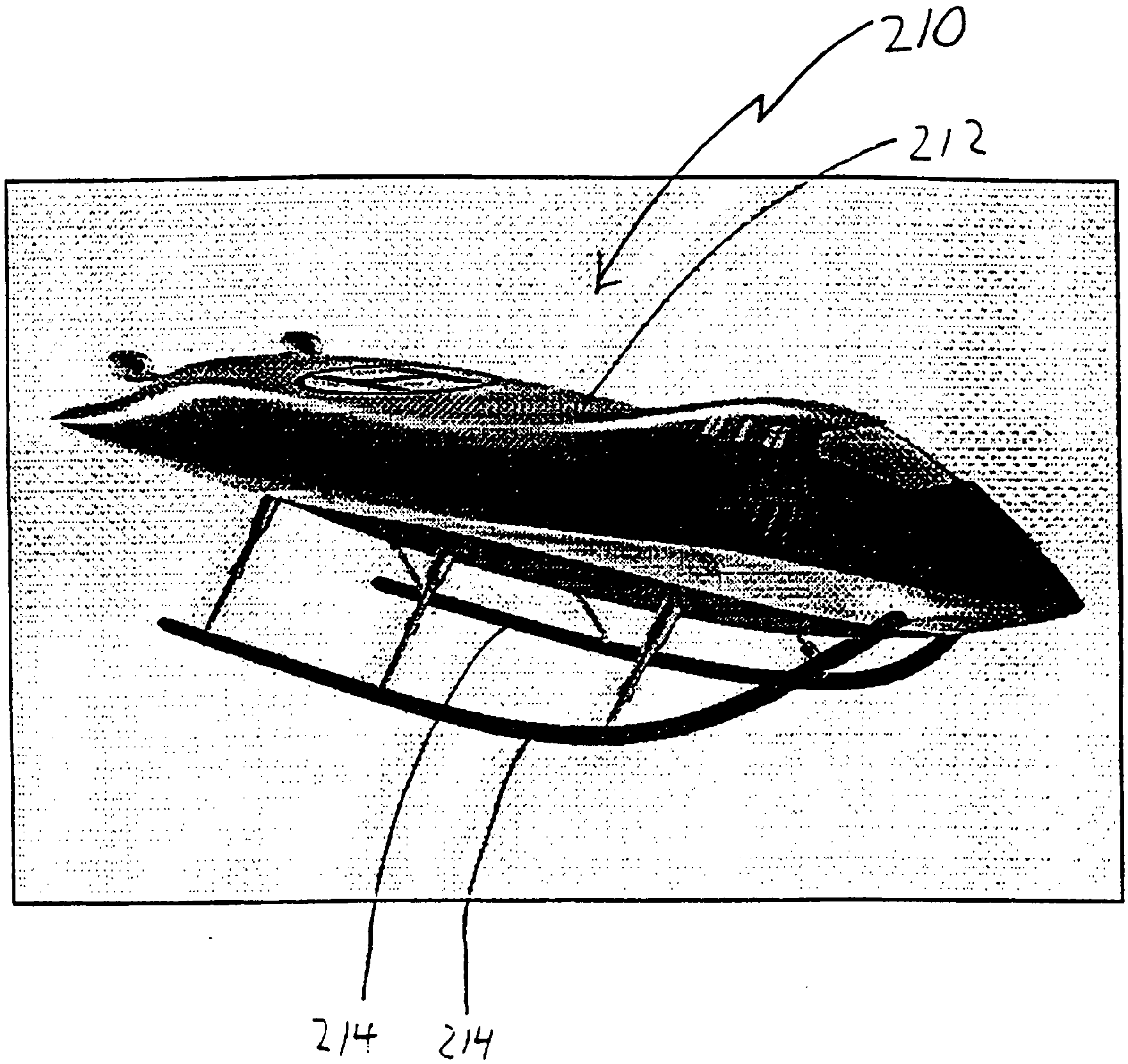


Fig.18

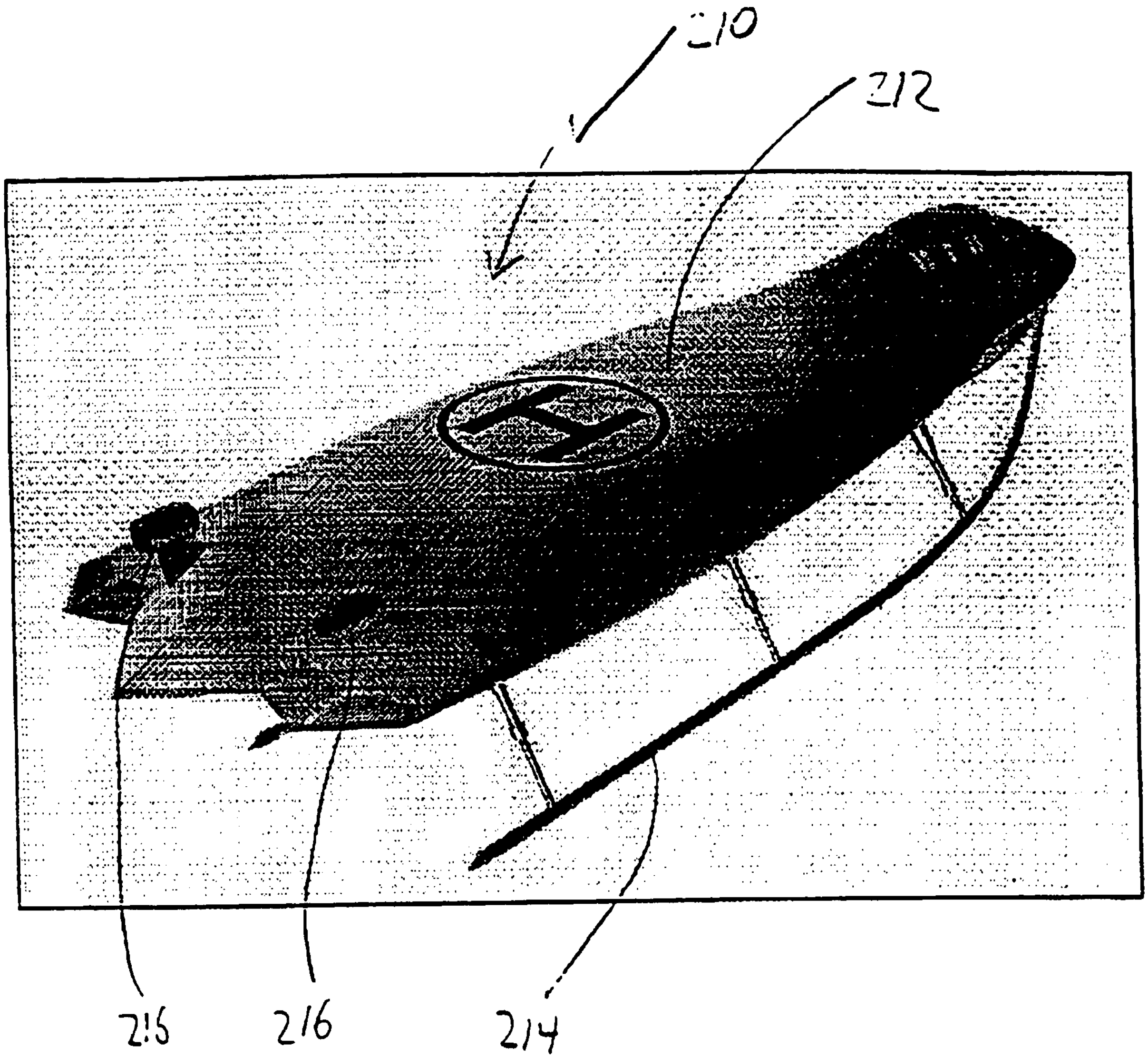


Fig.19

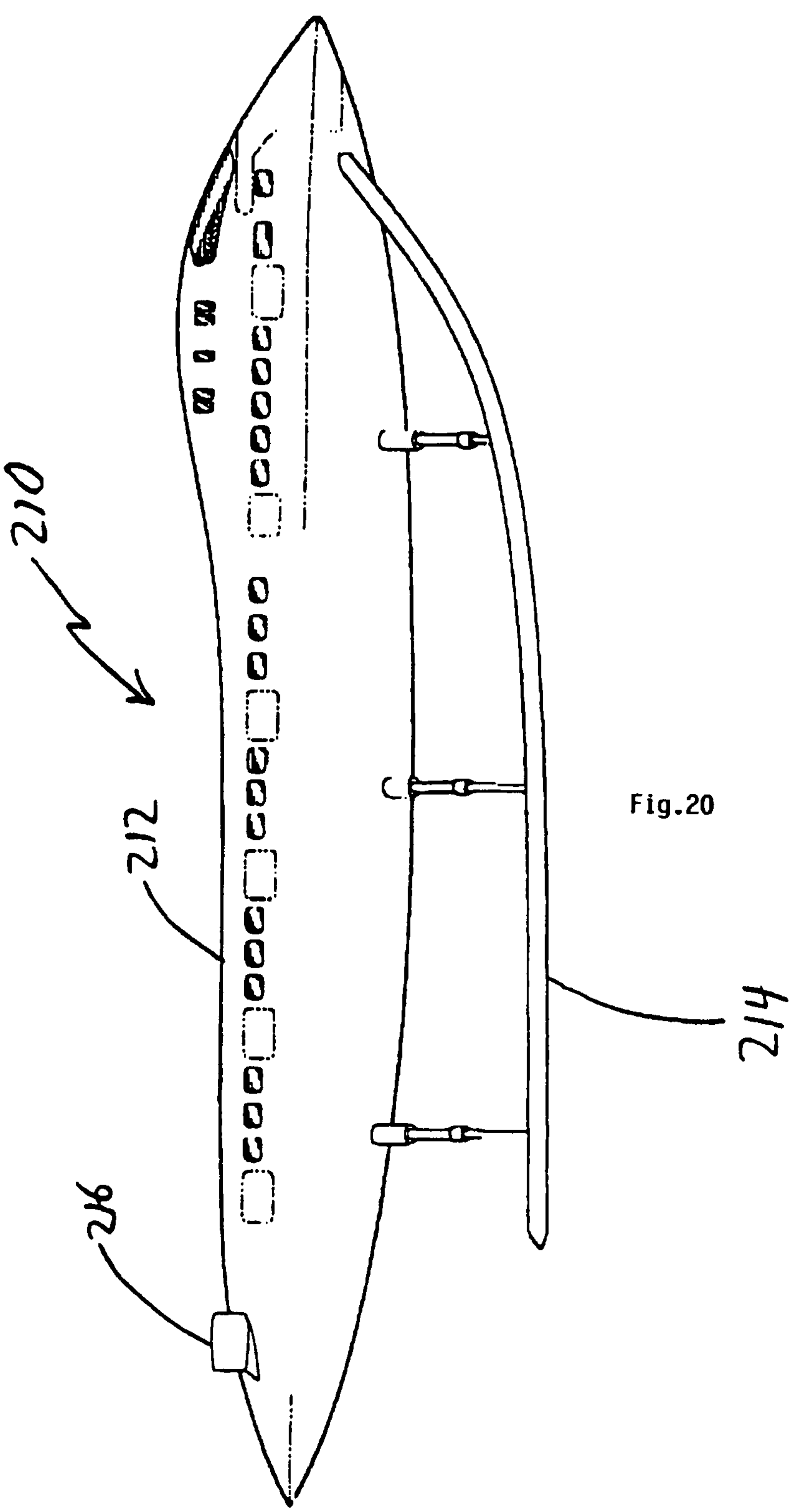


Fig.20

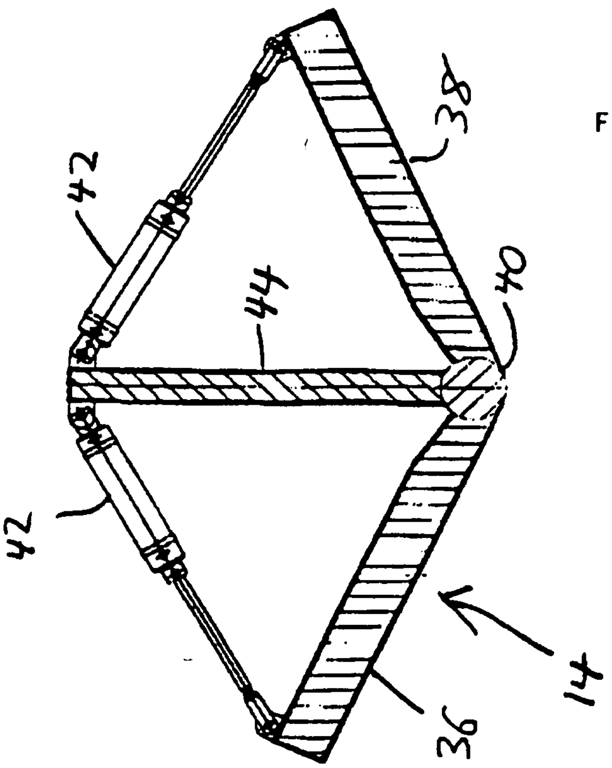


Fig. 22

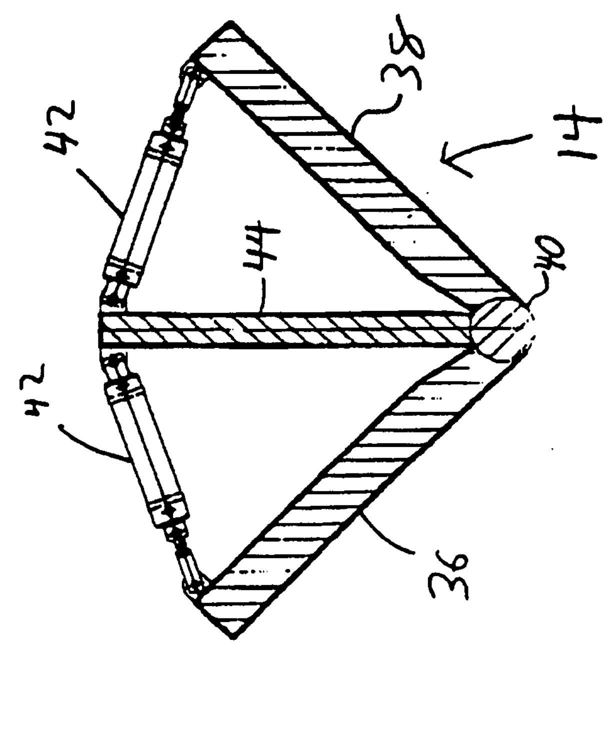


Fig.21

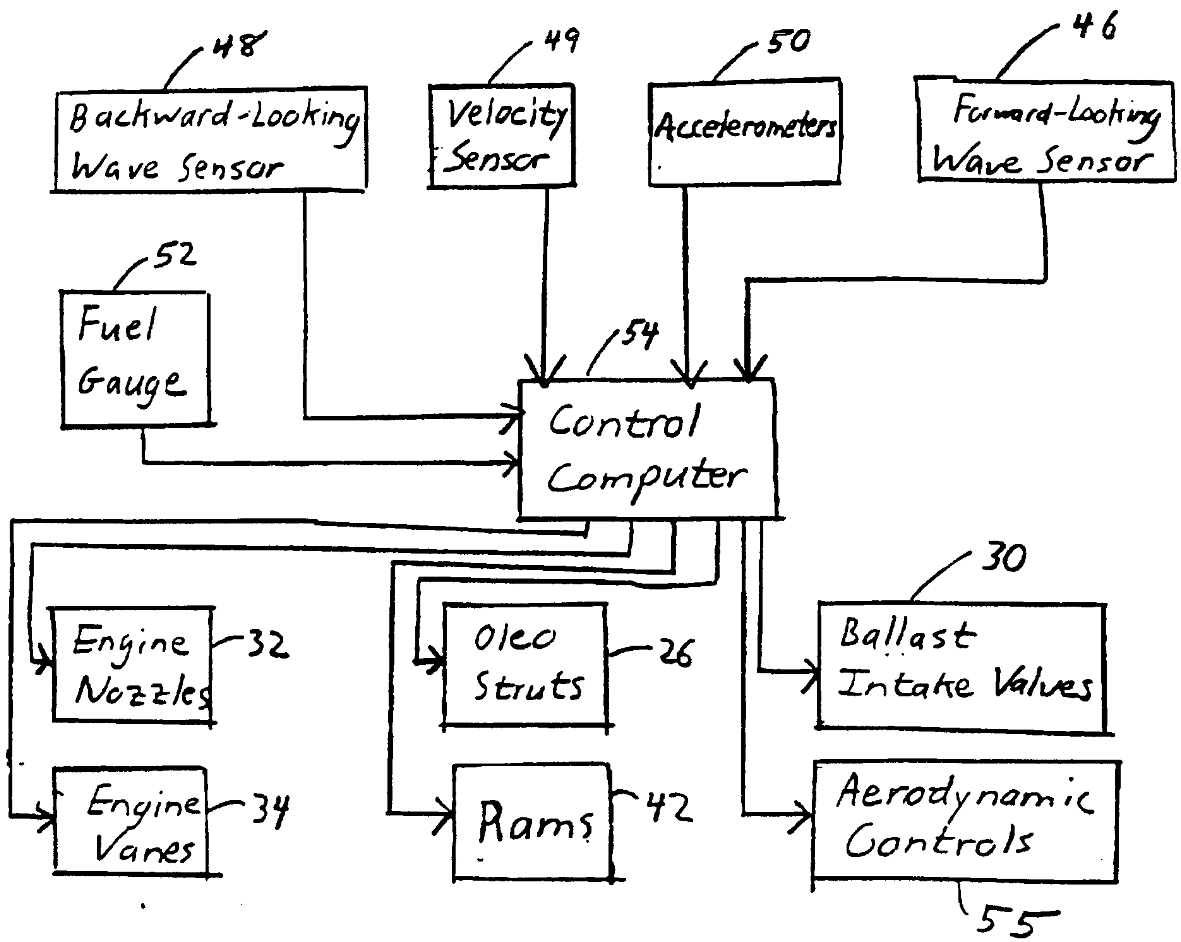
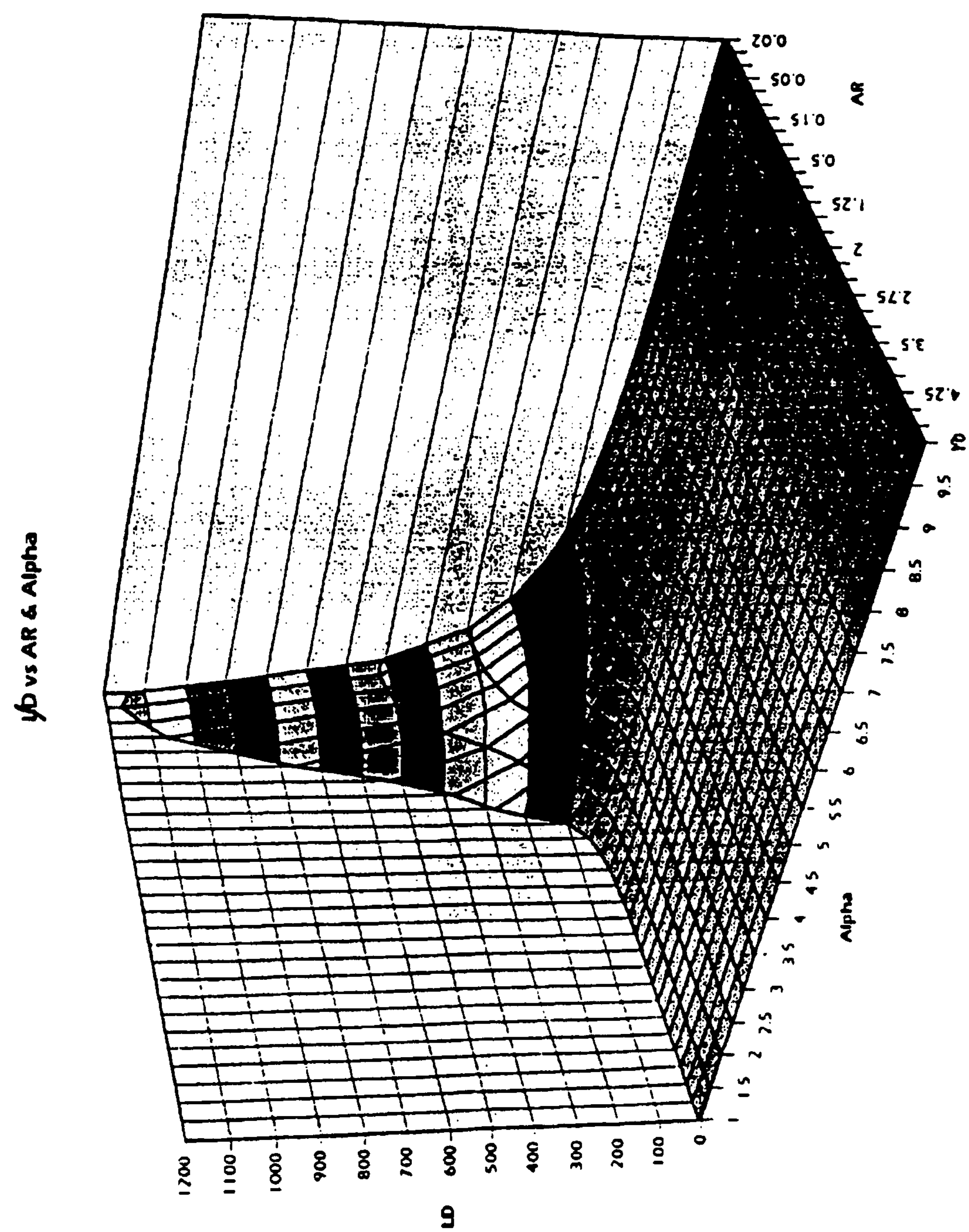

48
Backward-Looking Wave Sensor
49
Velocity Sensor
50
Accelerometers
46
Forward-Looking Wave Sensor
52
Fuel Gauge
54
Control Computer
30
Engine Nozzles
32
Oleo Struts
26
Ballast Intake Values
Engine Vanes
34
Rams
42
Aerodynamic Controls
55

Fig.23

Fig.24


vs AR & Alpha
AR
0.02
0.05
0.15
0.5
1.25
2
2.75
3.5
4.25
Alpha
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
LD
0
100
200
300
400
500
600
700
800
900
1000
1100
1200

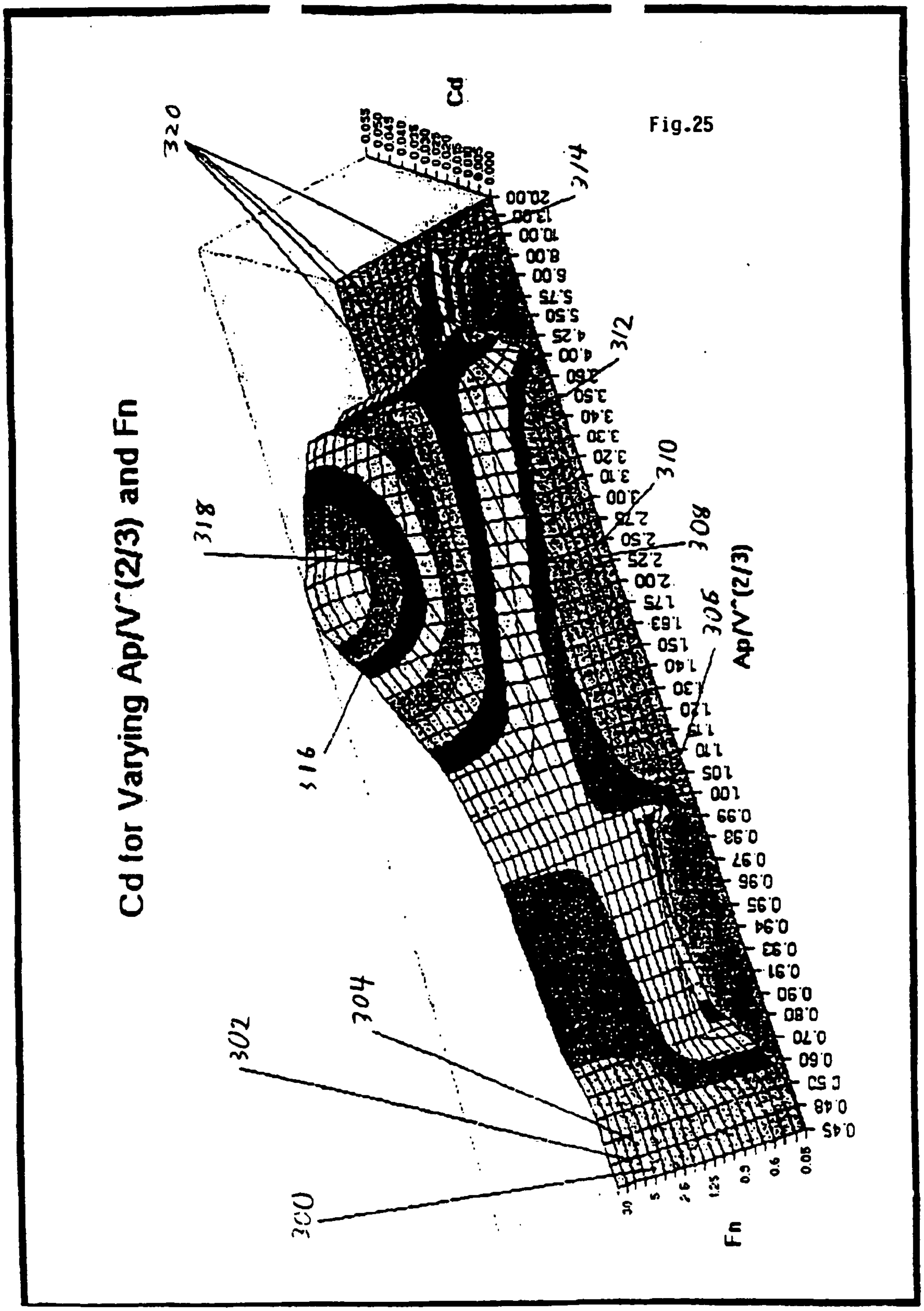

Cd for Varying Ap/V^(2/3) and Fn
Cd
Ap/V^(2/3)
Fn
300
302
304
306
308
310
312
314
316
318
320

Fig.25

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/14987

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B63B 1/20
US CL :114/283
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 114/283,61,121,125,144e,270-278 440/38-42 D12/300,310

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ------ Y	JP 62-244,778 A (YUKIO KAJINO) 26 OCTOBER 1987 SEE ENTIRE PATENT	11,15, 21-24 ------ 1-3,5-8,12,13,16-20, 25, 26
X ---- Y	US 5,619,944 A (BAKER) 15 APRIL 1997, SEE ENTIRE PATENT	11,14,20 ---- 1-8
X	US 5,265,550 A (HARPER, JR.) 30 NOVEMBER 1993, SEE ENTIRE PATENT	52-55,58, 59
X	US 4,685,641 A (KIRSCH ET AL.) 11 AUGUST 1987, SEE ENTIRE PATENT	52-56

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 NOVEMBER 1997	12 DEC 1997

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	ED SWINEHART
Facsimile No. (703) 305-3230	Telephone No. (703) 308-1113

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/149[illegible]

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US 2,647,709 A (DOOLITTLE ET AL.) 04 AUGUST 1953, SEE ENTIRE PATENT	27,28 ---- 29-31
Y	US 3,987,743 A (PENSEL) 26 OCTOBER 1976, SEE ENTIRE PATENT	9,10,19,20,25,26 29,30
Y	US 3,157,146 A (BILLIG) 17 NOVEMBER 1964, SEE ENTIRE PATENT	31

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/US9[illegible]4987

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 27-31,33-51 and 57
because they relate to subject matter not required to be searched by this Authority, namely:

The specification is objected to as failing to provide an adequate written description of the control arrangement of the thrust vectoring ystem and planing element supports responsive to sensed wave conditions.

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

CORRECTED VERSION*

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B63B 1/20	A1	(11) International Publication Number: WO 98/08732 (43) International Publication Date: 5 March 1998 (05.03.98)

(21) International Application Number: PCT/US97/14987

(22) International Filing Date: 26 August 1997 (26.08.97)

(30) Priority Data:
08/703,897 27 August 1996 (27.08.96) US

(71) Applicant: NEWPORT TECHNOLOGIES, LTD. [US/US]; 1151 Hilltop Drive, Redding, CA 96003 (US).

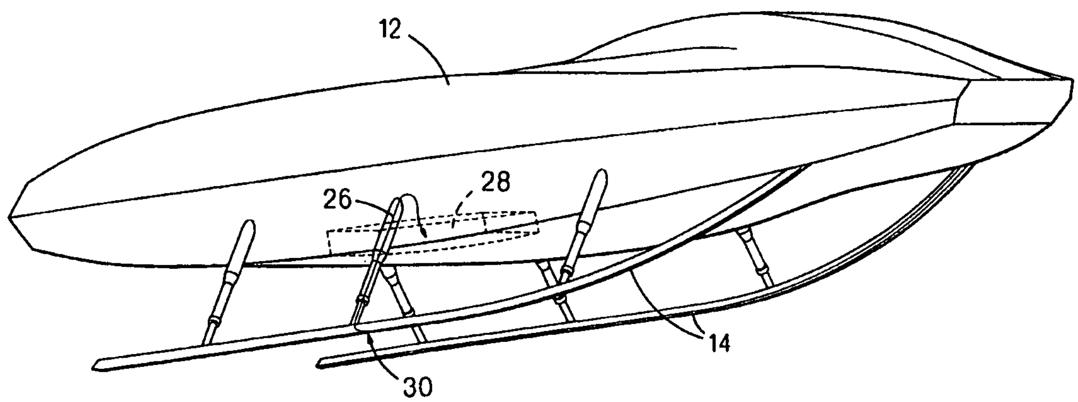
(72) Inventors: ROAKE, Richard, J.; 239A Eustis Avenue, Newport, RI 02840 (US). BAKER, Stephen, C.; 881 Fort Getty Road, Jamestown, RI 02835 (US).

(74) Agent: MROSE, James, E.; Fish & Richardson, P.C., 225 Franklin Street, Boston, MA 02110-2804 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: HYDROSKIING MARINE VESSEL



(57) Abstract

A marine vessel includes a buoyant vessel body (12), a propulsive device, and at least one planing element (14). The planing element lifts the buoyant vessel body upward and out of contact with water throughout prolonged high-speed travel. The ratio of the planing element area to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds is less than 1. The length of the planing element is at least 20 times its breadth. At least one of a plurality of attachment mechanisms (26) attached between the planing element and the buoyant vessel body is controllably adjustable in length so as to adjust an angle of attack of the planing element with respect to water. A deadrise angle adjustment mechanism (42) controllably adjusts a deadrise angle of the planing element with respect to water. The buoyant vessel body includes a ballast tank (28), and ballast piping connects the ballast tank with a ballast intake valve (30).

*(Referred to in PCT Gazette No. 26/1998, Section II)

HYDROSKIING MARINE VESSEL

Background of the Invention

This invention relates to marine vessels having hydroskis and more particularly relates to hydroskiing marine vessels capable of travel at very high speeds with active control of pitch, yaw, and roll and dynamic damping of impact loadings, wave loadings, and vibrations.

Marine vessels may be fitted with hydroskis for the purpose of lifting the buoyant vessel body out of contact with water at sufficiently high speeds, due to planing action of the hydroskis, thereby reducing hydrodynamic drag. Such a marine vessel can be steered by appropriate vectoring of the thrust of its propulsion system. During hydroskiing operation the hydroskis are displaced downwardly with respect to the buoyant vessel body but during low-speed operation of the marine vessel the hydroskis may be retracted upward such that the lower surfaces of the hydroskis form part of the lower surface of the hull of the marine vessel.

Summary of the Invention

One aspect of the invention features a marine vessel that includes a buoyant vessel body, a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed, and at least one planing element attached to the buoyant vessel body. The planing element or elements lift the buoyant vessel body upward and out of contact with water throughout prolonged high-speed travel of the marine vessel, by virtue of lifting action due to planing. The planing element or elements have a length and breadth that, when multiplied, define a planing element area (A_P). Each of the planing elements supports a weight that, when divided by mass density of water, defines a volumetric equivalent of the weight supported by the planing element (∇). The ratio

of the planing element area to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds $A_p/(\nabla^{2/3})$ is less than 1.

Applicant believes that when $A_p/(\nabla^{2/3})$ is less than 1 the coefficient of drag (C_d) due to planing of a hydroskiing marine vessel should be relatively low, given the froude number [F_n = speed/(gravitational acceleration x hull length)^{½}] at which such a vessel would be expected to operate. Because the coefficient of drag is low, such a vessel should be able to operate at high speeds with high energy efficiency.

According to another aspect of the invention the length of each of the planing elements is at least 20 times the breadth of the planing element. Applicant believes that the ratio of lift to drag (L/D) due to planing of a hydroskiing marine vessel is relatively high where the aspect ratio (AR) of breadth to length of the planing element is sufficiently low, assuming that the angle of attack (α) between the skis and the water is also sufficiently low. The high lift to drag ratio enables the marine vessel to operate at high speeds with high energy efficiency.

According to another aspect of the invention there are a plurality of attachment mechanisms attached to the planing element or elements and the buoyant vessel body. The attachment mechanisms have strength and rigidity sufficient to transmit lifting forces from the planing element or elements to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water. At least one of the attachment mechanisms is controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with the water, so as to adjust an angle of attack (α) of the planing

element or elements with respect to the water during the high-speed travel.

The ability to adjust the angle of attack (α) of the planing element or elements with respect to the water is advantageous because lift is a function of the angle of attack. In particular, lift (L) is equal to $\frac{1}{2}\rho v^2 A_W (dC_L/d\alpha)\alpha(\cos\beta)$, where ρ is the density of water, v is velocity of the marine vessel, A_W is the wetted area of the planing element at a given point in time, C_L is coefficient of lift, and β is the deadrise angle of the planing element. By appropriate adjustment of the angle of attack (α) it is possible to maintain a substantially constant lift, in a planing condition, over a broad range of speeds.

Another aspect of the invention provides a deadrise angle adjustment mechanism attached to the planing element or elements that controllably adjusts a deadrise angle (β) of the planing element or elements with respect to the water during the high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with the water. The ability to adjust the deadrise angle (β) of the planing element or elements with respect to the water is advantageous because lift is a function of the deadrise angle, as is discussed above. Thus, by appropriate adjustment of the deadrise angle (β) it is possible to maintain a substantially constant lift, in a planing condition, over a broad range of speeds.

Another aspect of the invention features one or more ballast tanks within the buoyant vessel body, one or more ballast intake valves, and ballast piping connecting the ballast tank or tanks with the ballast intake valve or valves. The ballast intake valve or valves controllably receive water during high-speed travel of the marine vessel to fill the ballast tank or tanks

through the ballast piping. The ballast tank or tanks make it possible to compensate for spent fuel with intake of water. By compensating for lost weight due to spent fuel it is possible to prevent undue lifting of the buoyant vessel body due to planing, which would result in inefficient operation of the marine vessel.

Another aspect of the invention features a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves, and a control system connected to the sensor system and to the propulsive device and configured to actively vector thrust from the propulsive device in response to the signal information from the sensor system. The active vectoring of thrust compensates for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

The sensor system may include, for example, an accelerometer that directly measures motion of the marine vessel due to waves, or a wave sensor that detects water waves before the waves interact with the marine vessel, or both of the above combined with a sensor that measures the velocity of the marine vessel (from which the time of impact of a wave on the planing element or elements can be determined). The active vectoring of thrust can provide a relatively smooth, stable ride of the marine vessel through turbulent water. The signal information from a wave sensor can include wave height information, in which case the control system can actively vector thrust from the propulsive device so as to operate the marine vessel in a "platforming" mode if the wave height is relatively low and in a "contouring" mode if the wave height is relatively high. The buoyant vessel body travels a more uniform height with respect to mean water level in the platforming mode than in the contouring mode

and travels a more uniform height with respect to actual water surface in the contouring mode than in the platforming mode.

According to another aspect of the invention at least one of the attachment mechanisms that transmit lifting forces from the planing element or elements to the buoyant vessel body includes a controllable dynamic force damper. The control system actively adjusts the controllable dynamic force damper in response to signal information from the sensor system to compensate for interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel. The active adjustment of the controllable dynamic force damper can provide a relatively smooth, stable ride of the marine vessel through turbulent water.

According to another aspect of the invention the planing elements have a configuration that permits the marine vessel to ground itself solely on the planing elements. Because the marine vessel can ground itself solely on the planing elements, the buoyant vessel body need not be constructed to withstand grounding contact between the buoyant vessel body itself and solid ground.

According to another aspect of the invention the attachment mechanisms are controllably adjustable to shift the planing element or elements between a high-speed position in which the planing element or elements are displaced in a downward direction relative to the buoyant vessel body during the high-speed travel of the marine vessel, and a docking position in which the planing element or elements are displaced sideways relative to the buoyant vessel body so as to serve as fenders during docking maneuvers of the marine vessel. Because the planing element or elements can serve as docking fenders, the buoyant vessel body need not be constructed to withstand contact with other objects.

Numerous other features, objects, and advantages of the invention will become apparent from the following detailed description when read in connection with the accompanying drawings.

Brief Description of the Drawings

Figs. 1-3 are perspective drawings of a hydroski marine vessel in accordance with the invention.

Fig. 4 is an elevational front view of the vessel of Figs. 1-3, illustrating operating and retracted positions of the hydroskis and operating and retracted positions of the take-off flaps.

Fig. 5 is an elevational side view of the vessel of Figs. 1-3, illustrating the range of available positions of the hydroskis due to active manipulation of the angle of attack of the hydroskis or due to the damping function of oleo struts.

Fig. 6 is a perspective drawing of the vessel of Figs. 1-3 illustrating a ballast tank, ballast intake, and ballast piping.

Fig. 7 is an elevational side view of the vessel of Figs. 1-3 illustrating vertical thrust vectoring of the vessel.

Fig. 8 is a plan view of the vessel of Figs. 1-3 illustrating directional thrust vectoring of the vessel.

Figs. 9 and 10 are perspective drawings of another hydroski marine vessel in accordance with the invention.

Fig. 11 is an elevational side view of the vessel of Figs. 9-10 illustrating internal components of the vessel.

Fig. 12 is a plan view of the vessel of Figs. 9-10 illustrating internal components of the vessel.

Fig. 13 is an elevational side view of the vessel of Figs. 9-10 with the hydroski retracted for buoyant operation of the vessel.

Fig. 14 is an elevational side view of the vessel of Figs. 9-10 with the hydroski and take-off flaps in their operating positions.

Fig. 15 is an elevational side view of the vessel of Figs. 9-10, illustrating variation in the position of the hydroskis due to active manipulation of the angle of attack of the hydroskis or due to the damping function of oleo struts.

Fig. 16 is a set of elevational side views of one of the engines of the vessel of Figs. 9-10 illustrating vertical thrust vectoring of the vessel.

Fig. 17 is a set of plan views of the engines of the vessel of Figs. 9-10 illustrating directional thrust vectoring of the vessel.

Figs. 18 and 19 are perspective drawings of another hydroski marine vessel in accordance with the invention.

Fig. 20 is an elevational side view of the vessel of Figs. 18 and 19.

Fig. 21 is a cross-sectional drawing of a hydroski for use with the vessels of Figs. 1-20, adjusted for a high deadrise angle of the hydroski with respect to the water.

Fig. 22 is a cross-sectional drawing of the hydroski if Fig. 21 adjusted for a lower deadrise angle of the hydroski with respect to the water.

Fig. 23 is a block diagram of a system for active thrust vectoring and active force damping for use with the vessels of Figs. 1-20.

Fig. 24 is a chart of lift to drag ratio L/D of a planing element as a function of the aspect ratio AR of the planing element and the angle of attack α of the planing element.

Fig. 25 is a drag map of coefficient of drag C_d of a marine vessel as a function of $A_p/(\nabla^{2/3})$ and as a function of froude number F_n.

Detailed Description

With reference to Figs. 1-3, marine vessel 10 includes buoyant vessel body 12 and hydroskis 14, upon which buoyant vessel body 12 travels at high speeds of between 158 and 250 knots (200 knots is normal). Engines 16, which may be, for example, Pratt and Whitney 4000 turbofan engines in a thrust class of about 90,000 lbs of thrust per engine, provide propulsive force to buoyant vessel body 12 while hydroskis 14 lift buoyant vessel body 12 upward and such that the buoyant vessel body is out of contact with water. At 200 knots, engines 16 are typically at 50-80% of available thrust. Alternatively, air propellers, ducted fans, turbines, turbofans, or other fluid momentum imparting devices may be used. Hydroskis 14 are non-buoyant and made of titanium or carbon fiber, but in alternative embodiments buoyant hydroskis or hydroskis made of other materials may be used. The dynamic lift from the hydroskis is sufficient to maintain the whole vessel in operating trim with the hydroskis planing on the surface of the water and cutting through waves.

Buoyant vessel body 12 is 410 feet long and has a fully-loaded weight of about 10,000-15,000 tons. Hydroskis 14 have a total length of 301.12 feet and a breadth of 4.76 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroskis is 0.0158 ("aspect ratio" as used herein refers to the breadth of a planing element divided by its length, regardless of whether the total length is wetted). As is illustrated in Fig. 24, taken from an article by Kerwin, Mandel, and Lewis (M.I.T.), Journal of Ship Research, 1972, the lift to drag ratio L/D of the hydroskis is relatively high when

the aspect ratio AR is low and the angle of attack α of the hydroskis (the longitudinal trim angle of the hydroskis relative to the water) is low (all points on this graph less than an aspect ratio of 0.25 are interpolated). In general, the length of the skis should be about 72-80% of the length of the boat and the skis should have a depth of about 8-12% of the length of the boat.

The planing element area A_p of each of the hydroskis is 1433 square feet ("planing element area" as used herein refers to the total length of a planing element multiplied by its breadth, regardless of whether the total length is wetted). Because the planing element area is relatively small compared to the dimensions of the vessel, the ratio of the planing element area to the volumetric equivalent of the weight supported by each planing element (one-half the total weight of the vessel) raised to the power of two-thirds [$A_p/(\nabla^{2/3})$] is less than 1. Fig. 25 shows the coefficient of drag C_d of a marine vessel as a function of $A_p/(\nabla^{2/3})$ and froude number F_n [speed/(gravitational acceleration x hull length)$^{1/2}$]. Reference number 300 on the drag map represents the vessel of Figs. 1-8 loaded to 15,000 tons and travelling at 165 knots. It can be seen that the coefficient of drag C_d is relatively low when $A_p/(\nabla^{2/3})$ is less than 1 and at froude numbers at which such a vessel would be expected to operate. More preferably, $A_p/(\nabla^{2/3})$ is less than 0.9, and even more preferably, less than 0.6. Below is a list of reference numbers on the drag map of Fig. 25 and the items they represent:

300: vessel of Figs. 1-8 at 15 kT and 165 kts;

302: 6,000 lb. Unlimited Hydroplane at 200 kts (temporary condition only on the order of a few seconds);

304: 180 lb. waterskier at 35 kts;

306: 60 kT Great Lakes Ore Carrier at 25 kts;

308: 9 kT Destroyer at 35 kts;
310: Torpedo 3 Human-Powered Sub at 6 kts;
312: 800 kT Supertanker at 25 kts;
314: IACC Yacht at 10 kts;
316: ADCAP Torpedo at 55 kts;
318: Mk50 Adv. Light Torpedo at 50 kts;
320: Clements & Blount Planning Boat.

Due to the minimization of hydrodynamic drag on the marine vessel, at most points in the high-speed operating range aerodynamic drag is substantially greater than hydrodynamic drag.

Referring to Fig. 4, during low-speed operation of the marine vessel hydroskis 14 are positioned as shown in dashed lines in order to reduce draft for entry into areas of water too shallow for the marine vessel to enter with the hydroskis in the operating position, in order to reduce drag while the marine vessel is travelling at buoyant or displacement speeds, and in order for the hydroskis to serve as "fenders" during docking maneuvers. During high-speed operation the hydroskis are positioned as shown in solid lines. The static water line during low-speed operation is represented by horizontal line 18, and the running water line during high-speed operation is represented by horizontal line 20. Hydroskis 14 may also be positioned in an intermediate position to permit grounding of the marine vessel on the hydroskis alone. The bottom of the buoyant vessel body can consequently have a relatively light construction.

In preparation for "take-off" of the marine vessel the hydroskis are moved to the high-speed position, and take-off flaps 22 are deployed in the operating position shown in solid lines in Fig. 4 (the flaps are also shown in the operating position in Fig. 2). The vessel accelerates at a pitch of about 6 degrees (with the skis pitched at 1.8 degrees relative to the vessel) in order

to maximize the lift coefficient. At about 40 or 45 knots the buoyant vessel body is lifted entirely out of contact with the water. As the vessel accelerates between 50 and 135 knots, the take-off flaps are slowly retracted to the position shown in dashed lines in Fig. 4, and the vessel slowly pitches down from 6 degrees to 0 degrees. The take-off flaps provide additional lift necessary to push the buoyant vessel body up and out of contact with the water below 135 knots.

With reference to Fig. 5, hydroskis 14 are attached to buoyant vessel body 12 by pivot 24 and oleo struts 26, which may be 2,000-ton rams, 45 feet in length and 8 feet in diameter, that use hydraulic oil, air, or rheologic fluid as a damping medium for the absorption or reduction of vibrations and shock loadings associated with acoustical noise, impact loadings or wave loadings or any other loadings on hydroskis 14. The dashed lines represent the range of positions of the longitudinal trim angle or angle of attack of hydroskis 14. This angle of attack can be adjusted in order to control the lift provided by the hydroskis, which is equal to $\frac{1}{2}\rho v^2 A_W (dC_L/d\alpha)\alpha(\cos\beta)$, where ρ is the density of water, v is velocity of the marine vessel, A_W is the wetted area of the planing element at a given point in time, C_L is coefficient of lift, and β is the deadrise (or dihedral) angle of the hydroskis. Also, oleo struts 26 can be dynamically controlled in order to compensate for unwanted forces experienced by the marine vessel due to interactions of the vessel with waves. Other hydraulic, electric or mechanical devices may be substituted for oleo struts 26. The oleo struts are also used to move the hydroskis between the high-speed position (solid lines in Fig. 4), the low-speed position (dashed lines in Fig. 4), and the intermediate "grounding" position.

Fig. 6 shows a ballast tank 28 in buoyant vessel body 12, and a ballast intake valve 30 is provided on one of hydroskis 14 to enable ballast tank 28 to be filled with water through ballast piping in oleo strut 26. Ballast tank 28 is actually one of a number of such ballast tanks within the buoyant vessel body, and ballast intake valve 30 is one of a number of such ballast intake valves on both hydroskis 14. As fuel is consumed by the marine vessel, ballast intake can be controlled by controlling the ballast intake valves so as to compensate for the lost weight with intake of water into the ballast tanks. This prevents undue lifting of the buoyant vessel body due to planing, which would result in inefficient operation of the marine vessel due to a decrease in the length of the water line and a corresponding increase in drag. A 10,000 ton boat might burn about 1,500 tons of fuel during a typical voyage.

With reference to Figs. 7 and 8, steering of the marine vessel can be accomplished through thrust vectoring of engines 16. The engines include rotatable divergent/convergent nozzles 32 in the exhaust plenum that can be adjusted to vector thrust upward up to about 20°, downward up to about 20°, or in a neutral position. Similarly, engines 16 also include rotatable vanes 34 in the exhaust plenum that can be adjusted to vector thrust to port up to about 20°, to starboard up to about 20°, or in a neutral position. In alternative embodiments the thrust provided by an engine or propulsive device can be vectored by other variable-geometry vanes, paddles, nozzles or other fluid momentum vectoring devices situated in the thrust stream and capable of being rotated about the desired axis to direct the thrust stream in a direction appropriate to the intended vectoring. In one such design a cone of interleaved petals is provided that can be directed up to about 20°

off of center in any given direction, the cone having a nozzle whose size can be varied by appropriate adjustment of the petals. Thrust vectoring can alternatively be accomplished by physical movement or rotation of the propulsive device itself.

Referring to Figs. 21 and 22, each hydroski 14 includes surface elements 36 and 38 pivotally connected about pivot 40. Rams 42, which may be hydraulic, air, or rheologic fluid-damped struts, are connected between surface elements 36 and 38 and a central vertical strut 44. Rams 42 can be adjusted to vary the deadrise angle β of hydroski 14 between a high value of 60 degrees or higher with respect to horizontal and a low value of 0 degrees with respect to horizontal and anywhere in-between. Figs 21 and 22 show two different configurations of the hydroski corresponding to two different deadrise angles. As is discussed above the lift provided by the hydroskis is proportional to the cosine of the deadrise angle β of the hydroskis, and thus lift can be controlled by controlling the deadrise angle through rams 42. At takeoff, the deadrise angle should be at 0 degrees, and at very high speed the deadrise angle should be high. Other hydraulic, electric or mechanical devices may be substituted for rams 42. The deadrise adjustment feature is the primary mechanism of compensation for overspeed or underspeed, which can result from interactions between the vessel and waves, aerodynamic forces, or decelerations due to maneuvering of the vessel, because this feature makes it possible to very easily relax or increase lift from the hydroskis. This ensures that the waterline length on the hydroskis stays at the correct value, and thus the center of lift of the vessel does not move backward or forward.

With reference to Fig. 23, the marine vessel is fitted with forward-looking wave sensor 46, backward-

looking wave sensor 48, velocity sensor 49, accelerometers 50, and fuel gauge 52, all of which transmit signal information to control computer 54. Based on this signal information the control computer actively controls nozzles 32 and vanes 34 of the engines, oleo struts 26 and rams 42, ballast intake valves 30, and aerodynamic controls 55 (including ailerons for roll control, elevons for pitch control, and speed brakes for speed reduction). Wave sensors 46 and 48 may include RADAR or millimeter-wave RADAR or LIDAR technology for determining the height, distance, and velocity of waves. Accelerometers 50 may be laser accelerometers.

In particular, in response to undesired accelerations of the marine vessel sensed by accelerometers 50 due to interactions between the vessel and waves, or in response to predicted impacts of waves on the hydroskis based on information provided by wave sensor 46 combined with vessel velocity as measured by velocity sensor 49, control computer 54 actively vectors thrust from the engines in an appropriate direction and amount so as to compensate for undesired movement of the vessel. The undesired acceleration may result in pitch (rotation about a transverse axis), yaw (rotation about a vertical axis), roll (rotation about a longitudinal axis), or change in velocity, or any combination thereof. In addition, control computer 54 can adjust aerodynamic controls 55 in response to undesired motion of the vessel.

The control computer 54 also, in response to undesired accelerations of the marine vessel sensed by accelerometers 50 (pitch, yaw, roll, change in velocity), or in response to predicted impacts of waves on the hydroskis based on information provided by wave sensor 46 combined with vessel velocity as measured by velocity sensor 49, actively adjusts oleo struts 26 and the

response rate of these struts so as to actively damp or reduce impact loadings and wave loadings, including wave impact loadings. Oleo struts 26 also inherently damp or reduce vibrations and loadings wholly apart from computer control. Immediately prior to a wave hit on one of the hydroskis, control computer 54 creates a differential pulse or force in one or more of oleo struts 26 in a direction opposite to the anticipated pulse created by the wave hit. Once the wave has hit the hydroski, control computer 54 softens residual forces in oleo struts 26, measured by accelerometers 50, in a similar manner. If the residual forces are directed upward, oleo struts 26 are caused to pull the hydroski upward; if the residual forces are directed downward, the oleo struts are caused to pull the hydroski downward.

Control computer 54 also adjusts oleo struts 26 to vary the angle of attack of the hydroskis and adjusts rams 42 to vary the deadrise angle of the hydroskis in order to provide a lift that is appropriate for a given speed of the marine vessel as measured by velocity meter 49. Thus, the hydroskis are capable of maintaining appropriate lift in a planing condition over a broad range of speeds. This is important because if the lift is too high the waterline length will decrease and consequently drag will increase.

During normal operation the marine vessel operates in a platforming mode of operation in which the buoyant vessel body travels at a constant height with respect to the mean water level. This is possible because thrust vectoring can overcome any pitching forces at a given speed where the wave height does not exceed the difference between flat water normal running trim and the bottom of the buoyant vessel body (i.e., where the waves will not crash into the buoyant vessel body). Thus, the

buoyant vessel body need not be constructed to withstand high-speed impacts from waves.

Furthermore, if the wave height detected by wave sensor 46 is such that the wave crests would be close to five feet from the bottom of the buoyant vessel body (in the case of a 410-foot vessel), or if an adverse weather report is received, then control computer 54 can shift from the standard platforming mode of operation to a contouring mode of operation, in which the buoyant vessel body travels at a constant height with respect to the actual water surface (or at least a more constant height with respect to the actual water surface than in the platforming mode), in order to prevent impact between the waves and the buoyant vessel body. Depending on the height of the waves, the control computer 54 may operate in an intermediate mode of operation in which contouring occurs only to the extent necessary to keep the crests of the waves more than five feet below the bottom of the buoyant vessel body. In other words, the skis go through the waves in this intermediate mode, but the marine vessel is actively pitched up and down by active thrust vectoring sufficiently to ensure that the bottom of the buoyant vessel body will never impact a wave. The contouring is accomplished by active thrust vectoring of engines 16. Also, during the contouring or intermediate mode of operation, control computer 54 causes the marine vessel to travel at an angle with respect to the waves. In particular, if the marine vessel is unable or might be unable to travel over a particular large wave having a height greater than a threshold value, the control computer causes the marine vessel to make a sharp pitching turn. The severity of the turn is proportional to the greater of two limiting factors: 1) the amount of time remaining before the particular large wave could impact the vessel, or 2) the size of the large wave,

which determines the amount of work required and hence the amount of time required, once the wave has reached the vessel, for the vessel to execute a contouring maneuver (contouring over the large wave) such that the buoyant vessel body does not impact the wave. The contouring and intermediate modes of operation are essentially emergency modes.

Control computer 54 can maintain a constant vessel weight by causing water to be introduced into the ballast tanks through ballast intake valves 30 in response to information received from fuel gauge 52 concerning fuel consumption. The maintenance of a constant vessel weight and a constant lift ensures a near constant waterline length of the marine vessel throughout the speed range of high-speed operation, which in turn minimizes drag.

During grounding of the marine vessel on the hydroskis, the control computer controls oleo struts 26 in response to information received from accelerometers 50 and forward-looking and backward-looking wave sensors 46 and 48, in order to compensate for undesired forces due to interaction between the marine vessel and waves. If a wave hit on the port side of the vessel is imminent, the oleo struts on the starboard side are stiffened and then relaxed slowly so as to absorb energy and to allow the vessel to shift gently toward the starboard side. Likewise, if a wave hit on the starboard side of the vessel is imminent, the oleo struts on the port side are stiffened and then relaxed slowly so as to absorb energy and to allow the vessel to shift gently toward the port side.

With reference to Figs. 9-12, another embodiment of a marine vessel 110 operates in the same manner as marine vessel 10 of Figs. 1-8 except as otherwise indicated below. The marine vessel includes buoyant vessel body 112 and a single hydroski 114, upon which

buoyant vessel body 112 travels at high speeds in the range of 300 knots. Engines 116 are in a thrust class of about 750 lbs of thrust per engine.

Buoyant vessel body 112 is 34 feet long and has a fully-loaded weight of about 6.26 tons. Hydroski 114 has a length of 24.97 feet and a breadth of 0.76 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroski is 0.03. The planing element area A_p of the hydroski is 18.98 square feet. Reference number 302 on the drag map of Fig. 25 represents the vessel of Figs. 9-17 loaded to 10,000 tons and travelling at 200 knots.

During low-speed operation of the marine vessel hydroski 114 is positioned as shown in Fig. 13. During high-speed operation the hydroski is positioned as shown in Fig. 14. The static water line during low-speed operation is represented by horizontal line 118, and the running water line during high-speed operation is represented by horizontal line 120.

In preparation for "take-off" of the marine vessel the hydroski is moved to the high-speed position, and take-off flaps 122, which are mounted on the wings of the vessel, are deployed in the operating position shown in solid lines in Fig. 14. As the vessel accelerates between 5 and 50 knots, the take-off flaps are slowly retracted to the position shown in dashed lines in Fig. 13. Take-off flaps 122 assist in stability during "take-off" and "landing" of the single-hydroski marine vessel.

Because the marine vessel has a single hydroski 114 it is highly maneuverable and capable of relatively sharp cornering. As thrust vectoring or aerodynamic controls or both cause the marine vessel to turn, the lift forces provided by the hydroski pushes the vessel into the turn in a banking maneuver.

With reference to Fig. 15, hydroski 114 is attached to buoyant vessel body 112 by pivot 124 and oleo

struts 126. Solid and dashed lines represent the range of positions of the longitudinal trim angle or angle of attack of hydroski 114.

With reference to Figs. 16 and 17, engines 116 include rotatable nozzles 132 that can be adjusted to vector thrust upward, downward, or in a neutral position. Similarly, engines 116 also include rotatable vanes 134 that can be adjusted to vector thrust to port, to starboard, or in a neutral position.

Referring to Figs. 18-20, another embodiment of a marine vessel 210 operates in the same manner as marine vessel 10 of Figs. 1-8 except as otherwise indicated below. The marine vessel includes buoyant vessel body 212 and a hydroskis 214, upon which buoyant vessel body 212 travels at high speeds of between 125 and 250 knots. Engines 216 are in a thrust class of about 90,000 lbs of thrust per engine.

Buoyant vessel body 212 is 300 feet long and has a fully-loaded weight of about 1,800 tons. Hydroskis 214 have a length of 220.3 feet and a breadth of 2.14 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroskis is 0.097. The planing element area A_P of the hydroskis is 942.88 square feet. Reference number 304 on the drag map of Fig. 25 represents the vessel of Figs. 18-20 loaded to 1,500 tons and travelling at 165 knots.

There have been described novel and improved apparatus and techniques for marine vessel hydroskiing. It is evident that those skilled in the art may now make numerous uses and modifications of and departures from the specific embodiments described herein without departing from the inventive concept. For example, it is possible to construct other marine vessels according to the invention having different dimensions and performance parameters, e.g., vessels with more powerful engines that

travel at substantially greater speeds than those described herein.

What is claimed is:

1. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed; and

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water throughout prolonged high-speed travel of the marine vessel by virtue of lifting action due to planing;

the planing element having a length and breadth that, when multiplied, define a planing element area;

the planing element supporting a weight that, when divided by mass density of water, defines a volumetric equivalent of the weight supported by the planing element;

the ratio of the planing element area to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds being less than 1.

2. The marine vessel of claim 1 wherein the ratio of the planing element area to the volumetric equivalent of the total weight of the marine vessel raised to the power of two-thirds is less than 0.9.

3. The marine vessel of claim 2 wherein the ratio of the planing element area to the volumetric equivalent of the total weight of the marine vessel raised to the power of two-thirds is less than 0.6.

4. The marine vessel of claim 1 wherein

there are a plurality of planing elements attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during

high-speed travel of the marine vessel, by virtue of lifting action due to planing;

each planing element has a length and breadth that, when multiplied, defines a planing element area;

each planing element supports a weight that, when divided by mass density of water, defines a volumetric equivalent of the weight supported by the planing element;

the weight supported by each planing element is a portion of total weight supported by the plurality of planing elements; and

the ratio of the planing element area of each of the planing elements to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds is less than 1 throughout prolonged high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with water.

5. The marine vessel of claim 1 wherein the propulsive device is attached directly to the buoyant vessel body.

6. The marine vessel of claim 1 wherein the high speed is greater than 100 knots.

7. The marine vessel of claim 6 wherein the high speed is greater than 150 knots.

8. The marine vessel of claim 1 wherein the prolonged high-speed travel has a duration on the order of one or more hours.

9. The marine vessel of claim 1 wherein the at least one planing element is buoyant.

10. The marine vessel of claim 1 wherein the at least one planing element is non-buoyant.

11. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed; and

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;

the planing element having a length and a breadth such that the length of the planing element is at least 20 times the breadth of the planing element.

12. The marine vessel of claim 11 wherein the length of the planing element is at least 40 times the breadth of the planing element.

13. The marine vessel of claim 12 wherein the length of the planing element is at least 100 times the breadth of the planing element.

14. The marine vessel of claim 11 wherein

there are a plurality of planing elements attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and

each planing element has a length and a breadth such that the length of the planing element is at least 20 times the breadth of the planing element.

15. The marine vessel of claim 11 wherein the propulsive device is attached directly to the buoyant vessel body.

16. The marine vessel of claim 11 wherein the high speed is greater than 100 knots.

17. The marine vessel of claim 16 wherein the high speed is greater than 150 knots.

18. The marine vessel of claim 11 wherein the prolonged high-speed travel has a duration on the order of one or more hours.

19. The marine vessel of claim 11 wherein the at least one planing element is buoyant.

20. The marine vessel of claim 11 wherein the at least one planing element is non-buoyant.

21. A hydroski assembly comprising:

a hydroski defining a planing surface to lift a buoyant vessel body of a marine vessel upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and

a plurality of attachment mechanisms attached to the hydroski and constructed for attachment to the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the hydroski to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

at least one of the attachment mechanisms being controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant vessel

body is lifted upward and out of contact with the water, so as to adjust an angle of attack of the hydroski with respect to the water during the high-speed travel.

22. The hydroski assembly of claim 21 wherein the attachment mechanism that is controllably adjustable in length comprises a strut.

23. The hydroski assembly of claim 22 wherein the strut is an oleo strut that is controllably adjustable in length.

24. The hydroski assembly of claim 21 wherein one of the attachment mechanisms other than the attachment mechanism that is controllably adjustable in length comprises a pivot mechanism constructed for direct attachment of the hydroski to the buoyant vessel body through the pivot mechanism.

25. The hydroski assembly of claim 21 wherein the hydroski is buoyant.

26. The hydroski assembly of claim 21 wherein the hydroski is non-buoyant.

27. A hydroski assembly comprising:

a hydroski defining a planing surface to lift a buoyant vessel body of a marine vessel upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and

a deadrise angle adjustment mechanism attached to the hydroski and constructed to controllably adjust a deadrise angle of the hydroski with respect to the water during the high-speed travel of the marine vessel in

which the buoyant vessel body is lifted upward and out of contact with the water.

28. The hydroski assembly of claim 27 wherein:

the hydroski comprises a plurality of surface elements extending the length of the hydroski, the plurality of surface elements being pivotally attached to each other along the length of the hydroski about at least one pivot; and

the deadrise angle adjustment mechanism comprises a plurality of struts, attached to the surface elements of the hydroski, that are controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with the water, so as to adjust an angle between the surface elements about the pivot to vary a deadrise angle of the hydroski with respect to the water during the high-speed travel.

29. The hydroski assembly of claim 27 wherein the hydroski is buoyant.

30. The hydroski assembly of claim 27 wherein the hydroski is non-buoyant.

31. The hydroski assembly of claim 27 further comprising a plurality of attachment mechanisms attached to the hydroski and constructed for attachment to the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the hydroski to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water, at least one of the attachment mechanisms being controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant

vessel body is lifted upward and out of contact with the water, so as to adjust an angle of attack of the hydroski with respect to the water during the high-speed travel.

32. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;

at least one ballast tank within the buoyant vessel body;

at least one ballast intake valve; and

ballast piping connecting the ballast tank with the ballast intake valve;

the ballast intake valve being arranged to controllably receive water during high-speed travel of the marine vessel to fill the ballast tank through the ballast piping.

33. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;

a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves;

a control system connected to the sensor system and to the propulsive device and configured to actively vector thrust from the propulsive device in response to the signal information from the sensor system to compensate for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

34. The marine vessel of claim 33 wherein the sensor system comprises at least one accelerometer that directly measures motion of the marine vessel due to waves.

35. The marine vessel of claim 33 wherein the sensor system comprises a wave sensor that detects water waves, and wherein the signal information provided by the sensor system comprises information from which anticipated motion of the marine vessel due to water waves can be predicted.

36. The marine vessel of claim 33 wherein the propulsive device comprises a plurality of independent propulsion units controlled by the control system.

37. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises pitch motion.

38. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises yaw motion.

39. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises roll motion.

40. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises a change in velocity.

41. The marine vessel of claim 33 further comprising a directional control system connected to the propulsive device to actively vector thrust from the propulsive device to steer the marine vessel.

42. The marine vessel of claim 33 wherein the signal information pertaining to interaction between the marine vessel and the water waves comprises wave height information, and wherein the control system is configured to actively vector thrust from the propulsive device so as to operate the marine vessel in a platforming mode if the wave height is relatively low and in a contouring mode if the wave height is relatively high, the buoyant vessel body travelling a more uniform height with respect to mean water level in the platforming mode than in the contouring mode and travelling a more uniform height with respect to actual water surface in the contouring mode than in the platforming mode.

43. The marine vessel of claim 42 wherein the control system is configured to actively vector thrust from the propulsive device so as to operate the marine vessel in an intermediate mode if the wave height is intermediate, the buoyant vessel body, in the intermediate mode, travelling a more uniform height with respect to mean water level than in the contouring mode but a less uniform height with respect to mean water level than in the platforming mode, and travelling a more uniform height with respect to actual water surface than in the platforming mode but a less uniform height with

respect to actual water surface than in the contouring mode.

44. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;

a plurality of attachment mechanisms attached to the planing element and the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the planing element to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

at least one of the attachment mechanisms comprising a controllable dynamic force damper;

a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves;

a control system connected to the sensor system and to the controllable dynamic force damper and configured to actively adjust the controllable dynamic force damper in response to the signal information from the sensor system to compensate for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

45. The marine vessel of claim 44 wherein the controllable dynamic force damper dynamically dampens loadings and vibrations experienced by the planing

element apart from adjustment of the controllable dynamic force damper by the control system.

46. The marine vessel of claim 44 wherein the attachment mechanism that comprises the controllable dynamic force damper comprises a strut.

47. The marine vessel of claim 44 wherein one of the attachment mechanisms other than the attachment mechanism that comprises the controllable dynamic force damper comprises a pivot mechanism constructed for direct attachment of the hydroski to the buoyant vessel body through the pivot mechanism.

48. The marine vessel of claim 44 wherein the high speed is greater than 100 knots.

49. The marine vessel of claim 48 wherein the high speed is greater than 150 knots.

50. The marine vessel of claim 44 wherein the planing element is buoyant.

51. The marine vessel of claim 44 wherein the planing element is non-buoyant.

52. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;

a plurality of planing elements attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action; and

a plurality of attachment mechanisms attached to the planing elements and the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the planing elements to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

the planing elements having a configuration that permits the marine vessel to ground itself solely on the planing elements.

53. The marine vessel of claim 52 wherein the attachment mechanisms are controllably adjustable to shift the planing elements between a high-speed position in which the planing elements are displaced in a downward direction relative to the buoyant vessel body during the high-speed travel of the marine vessel, and a low-draft position in which the planing elements are retracted upwardly so as to reduce draft for entry of the marine vessel into shallow water.

54. The marine vessel of claim 53 wherein the configuration of the planing elements that permits the marine vessel to ground itself solely on the planing elements is the low-draft position.

55. The marine vessel of claim 53 wherein the low-draft position of the planing elements reduces hydrodynamic drag during low-speed operation of the marine vessel in which the buoyant vessel body is in contact with water.

56. The marine vessel of claim 52 wherein at least one of the attachment mechanisms comprises a dynamic force damper.

57. The marine vessel of claim 56 further comprising:

a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves during grounding of the marine vessel;

a control system connected to the sensor system and to the dynamic force damper and configured to adjust the dynamic force damper in response to the signal information from the sensor system to compensate for the interaction between the marine vessel and the water waves during the grounding of the marine vessel.

58. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;

at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action; and

a plurality of attachment mechanisms attached to the planing element and the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the planing element to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

the attachment mechanisms being controllably adjustable to shift the planing element between a high-speed position in which the planing element is displaced in a downward direction relative to the buoyant vessel body during the high-speed travel of the marine vessel, and a docking position in which the planing element is displaced sideways relative to the buoyant vessel body so

as to serve as a fender during docking maneuvers of the marine vessel.

59. The marine vessel of claim 58 wherein the at least one planing element comprises a plurality of planing elements.

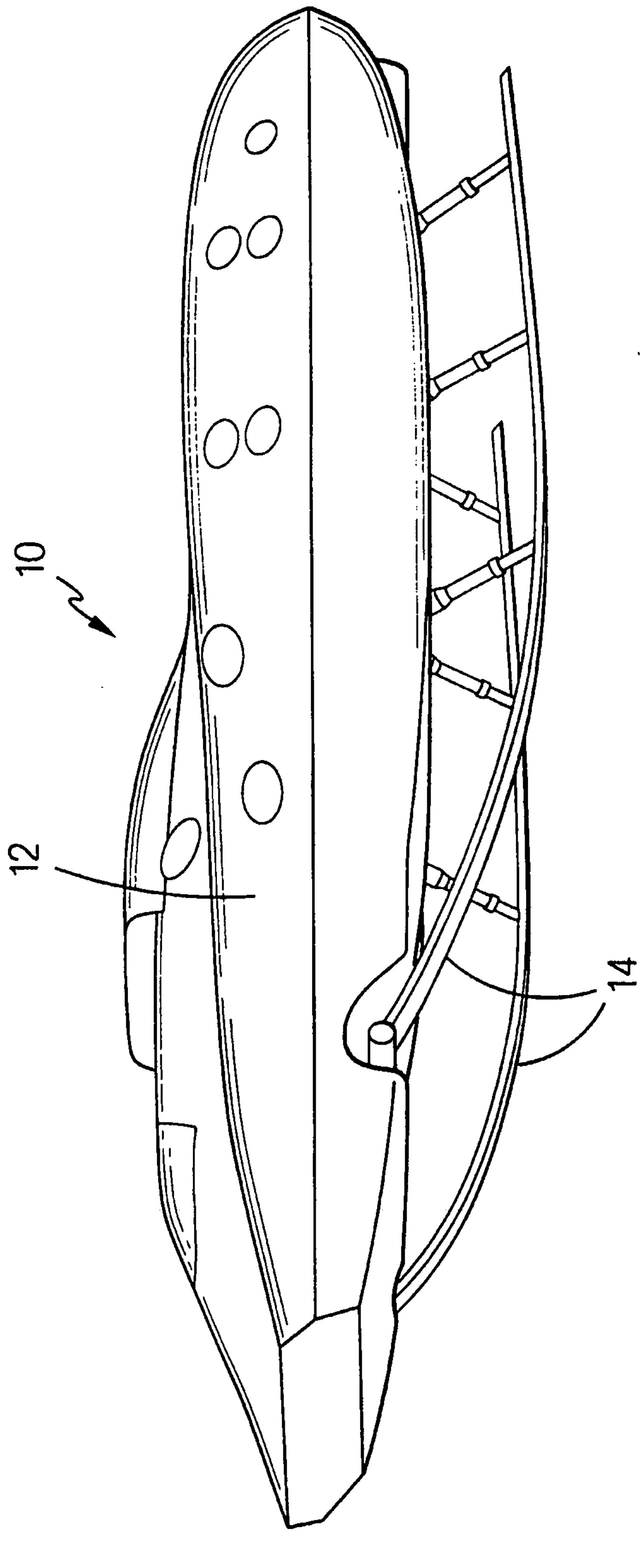


FIG. 1

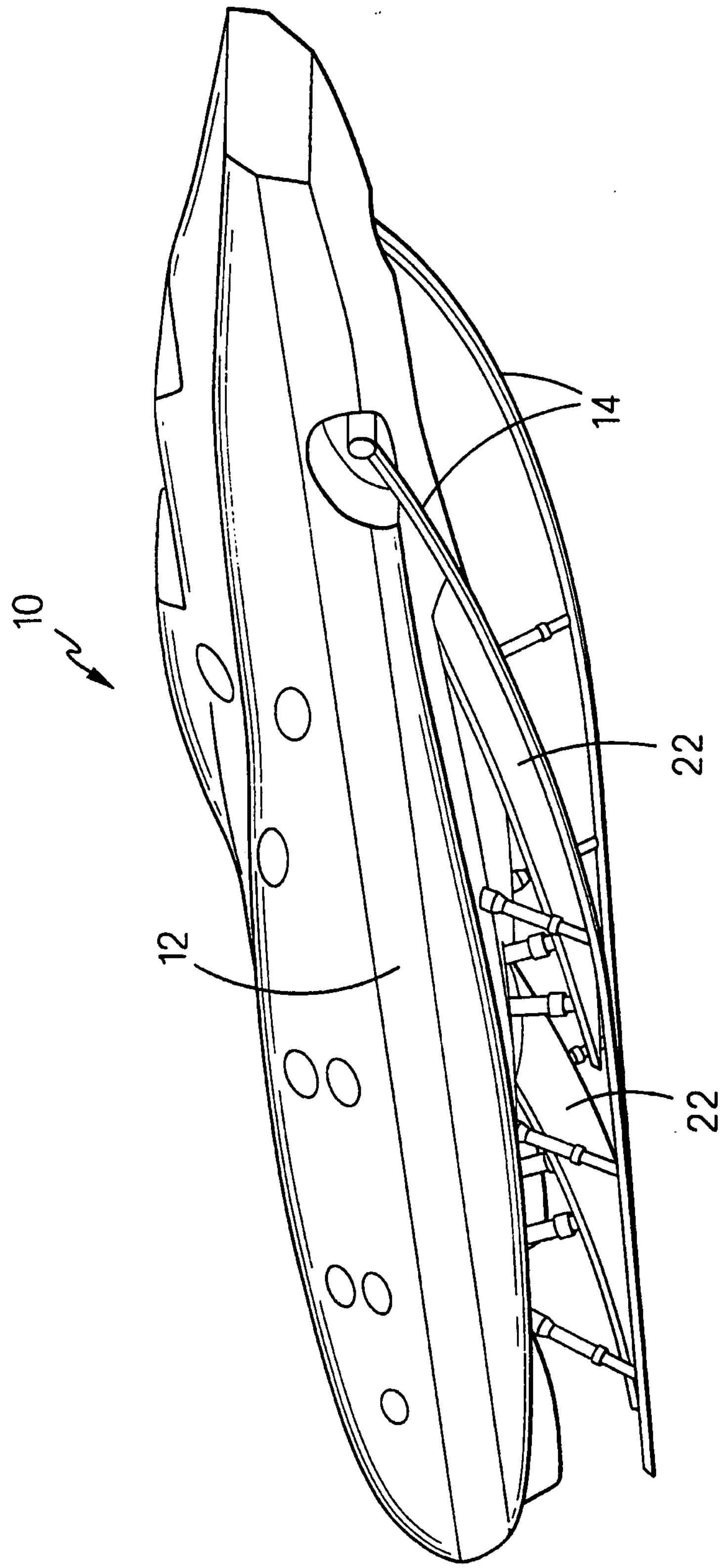


FIG. 2

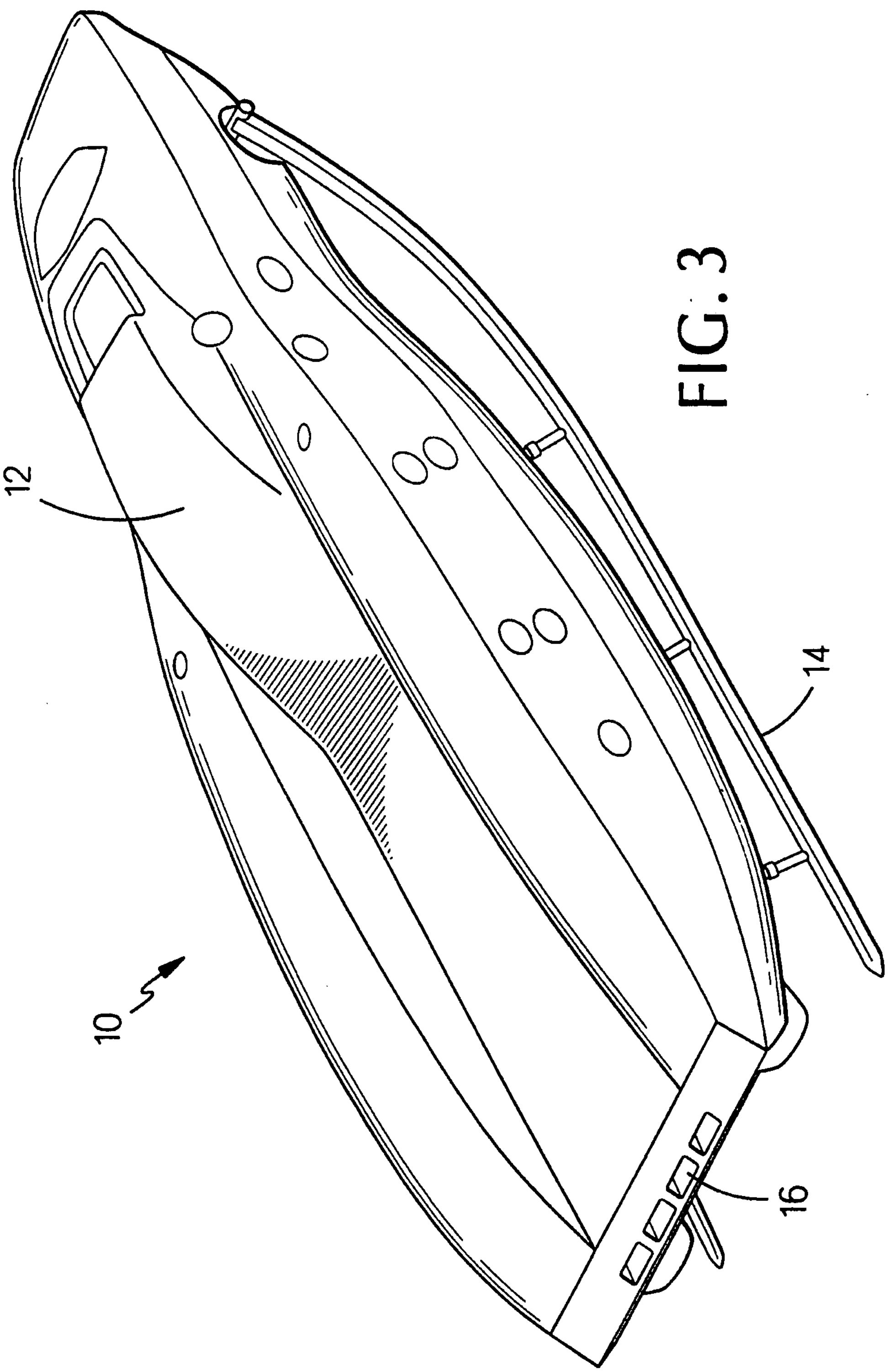


FIG. 3

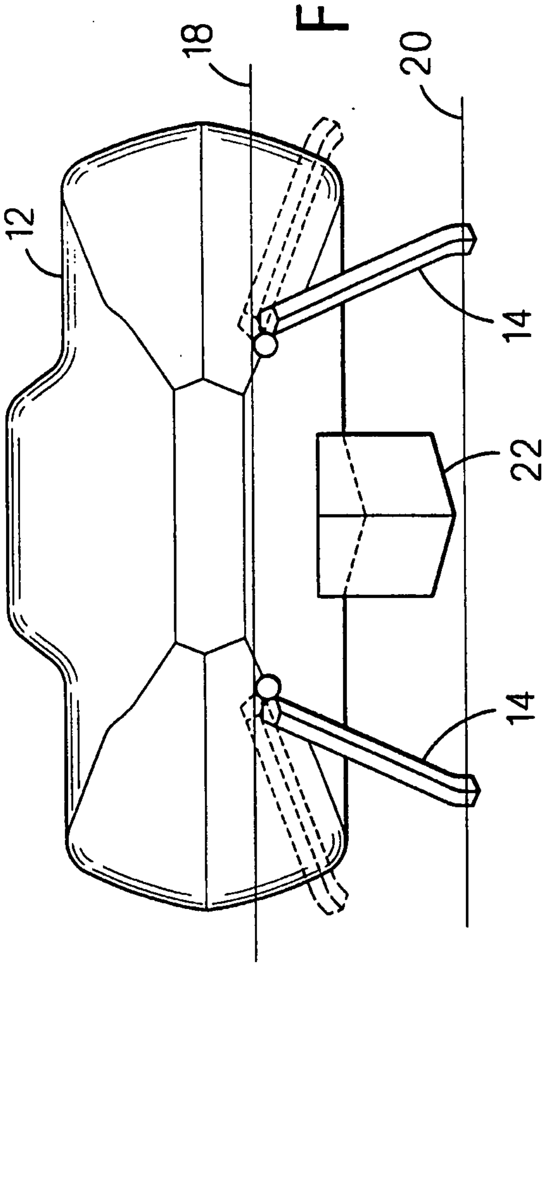


FIG. 4

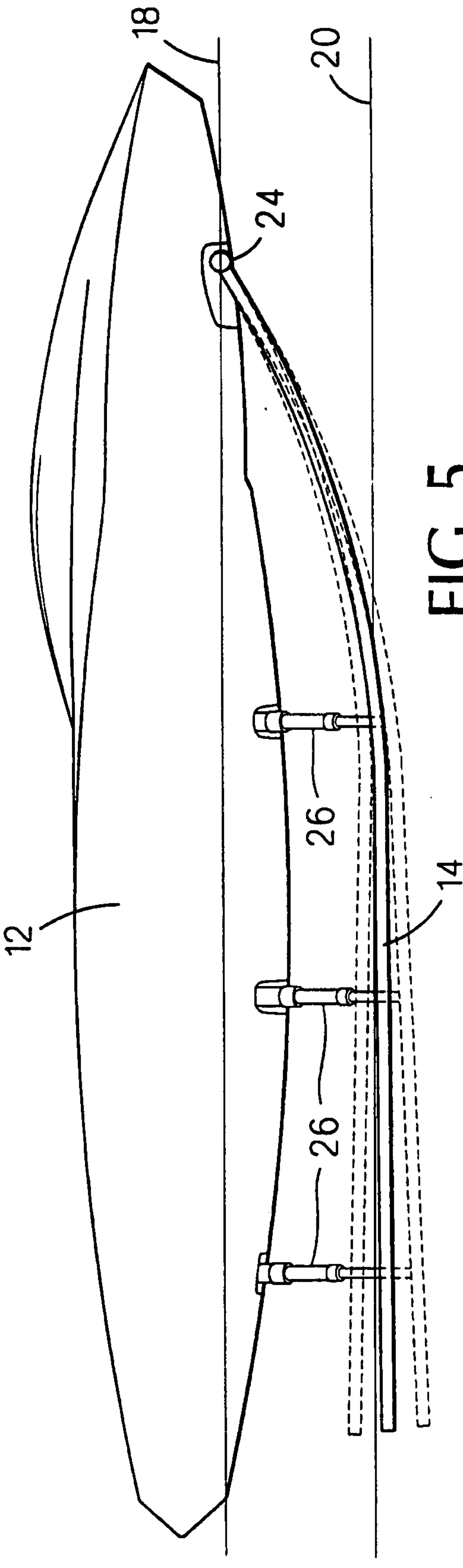


FIG. 5

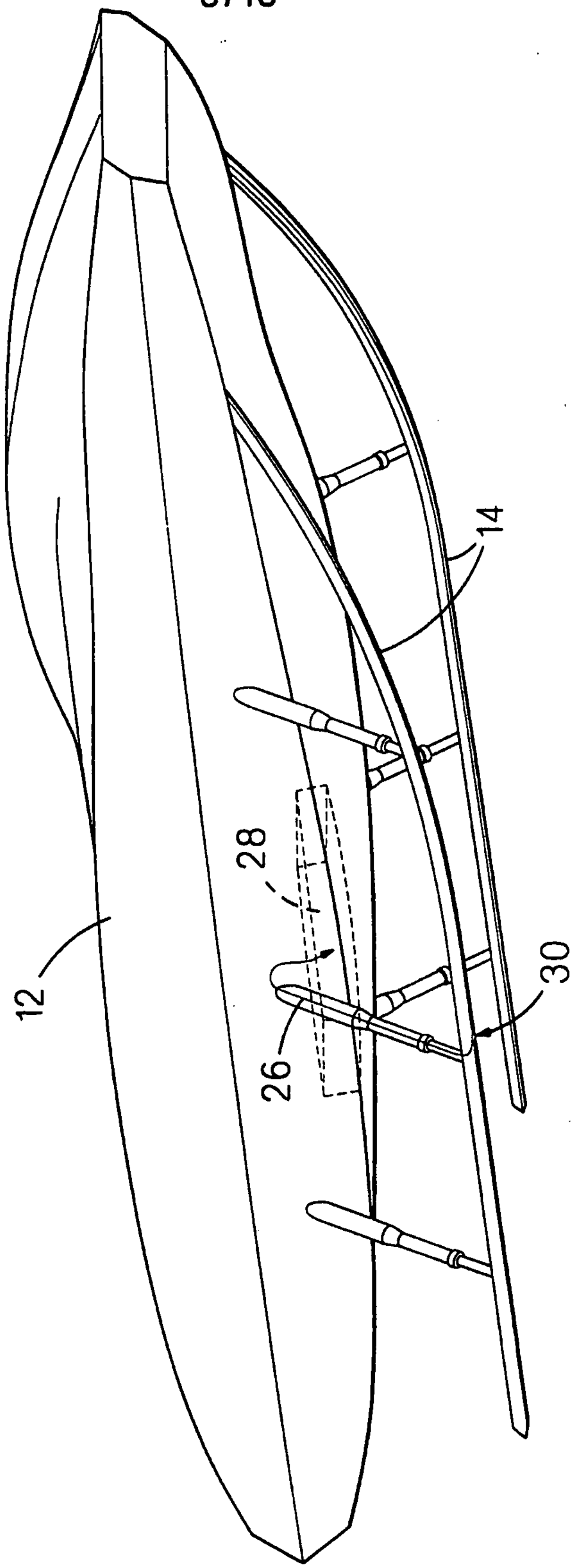


FIG.6

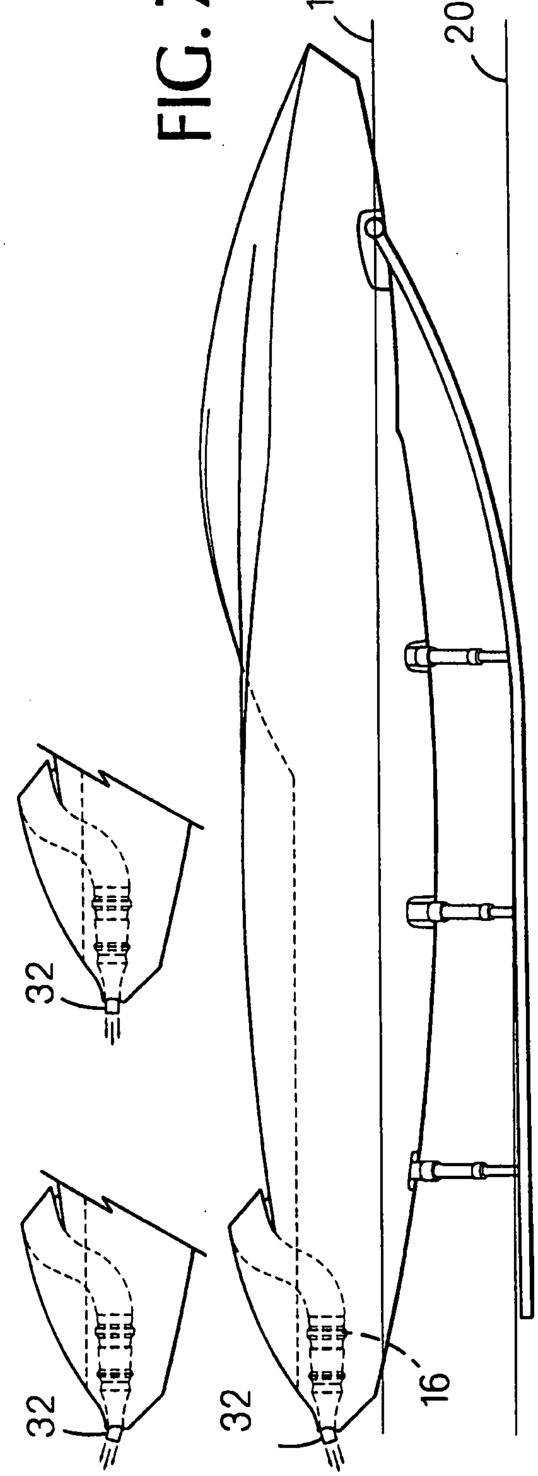


FIG. 7

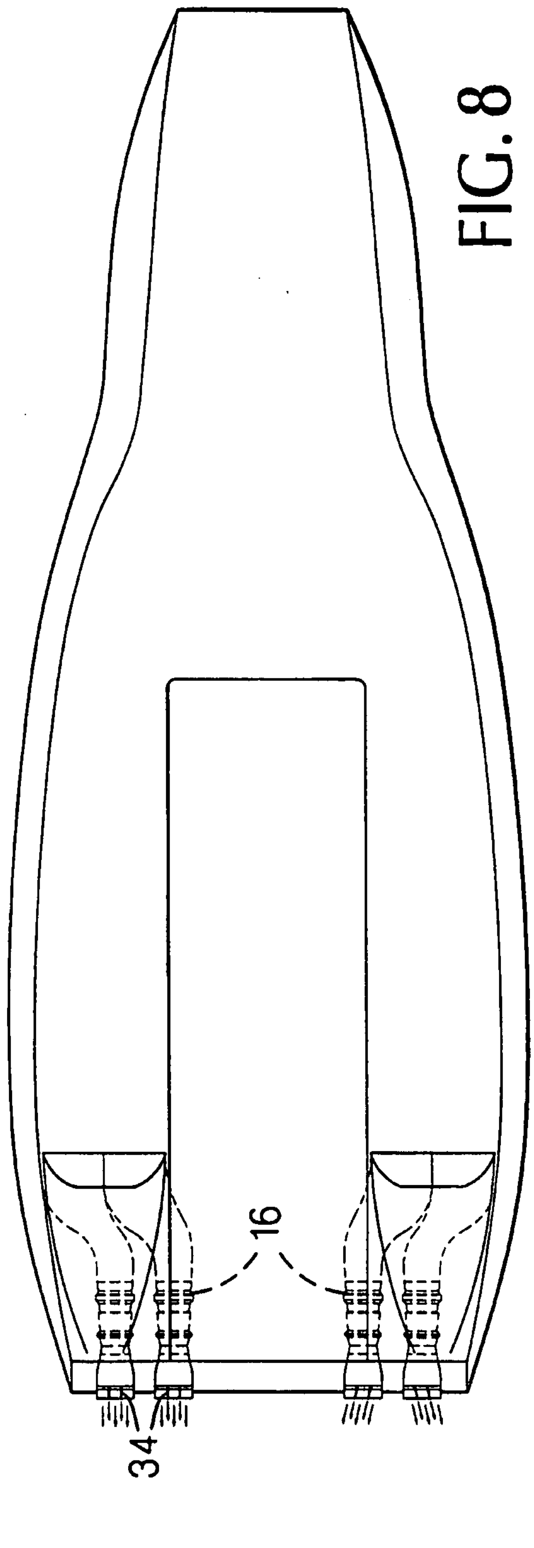


FIG. 8

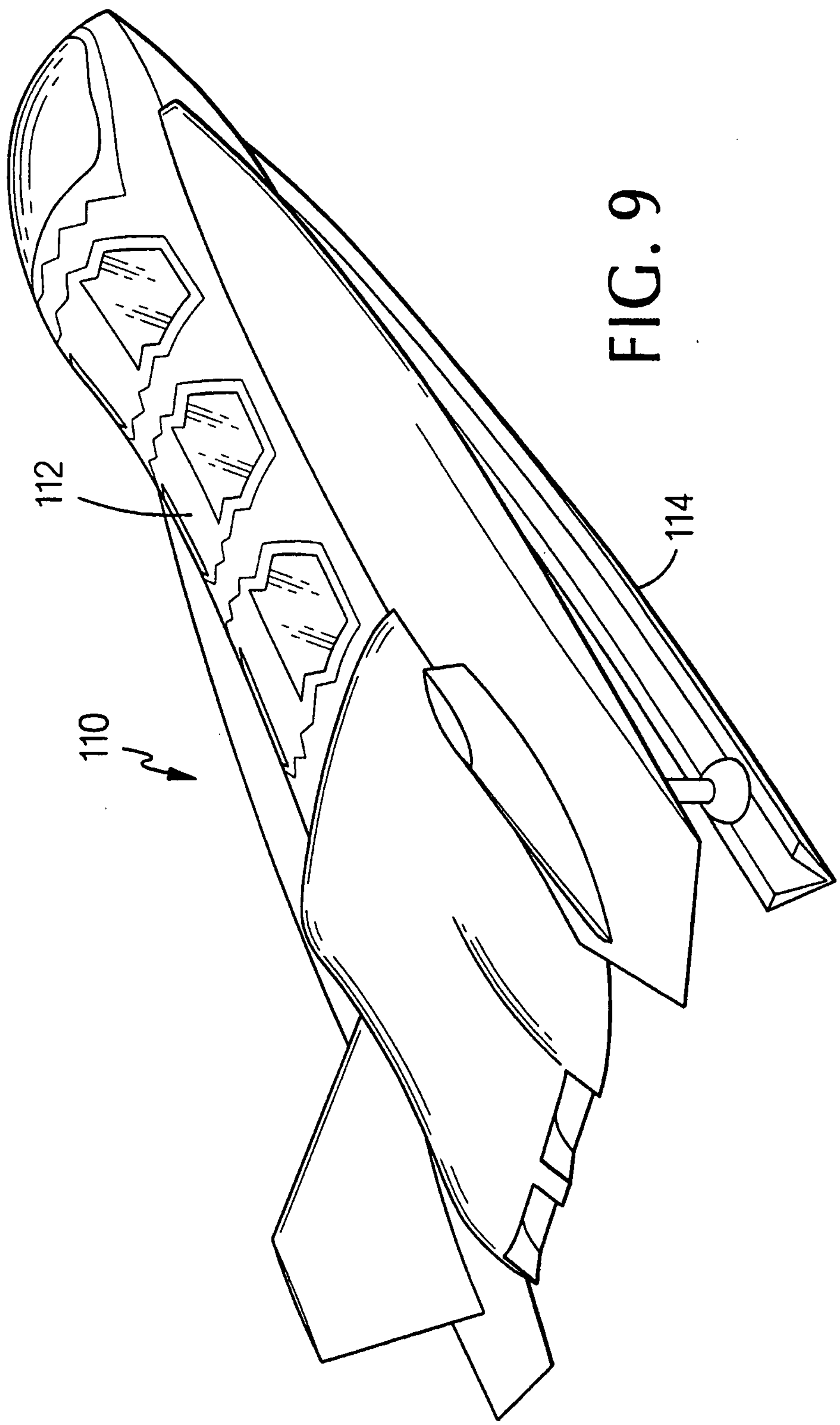


FIG. 9

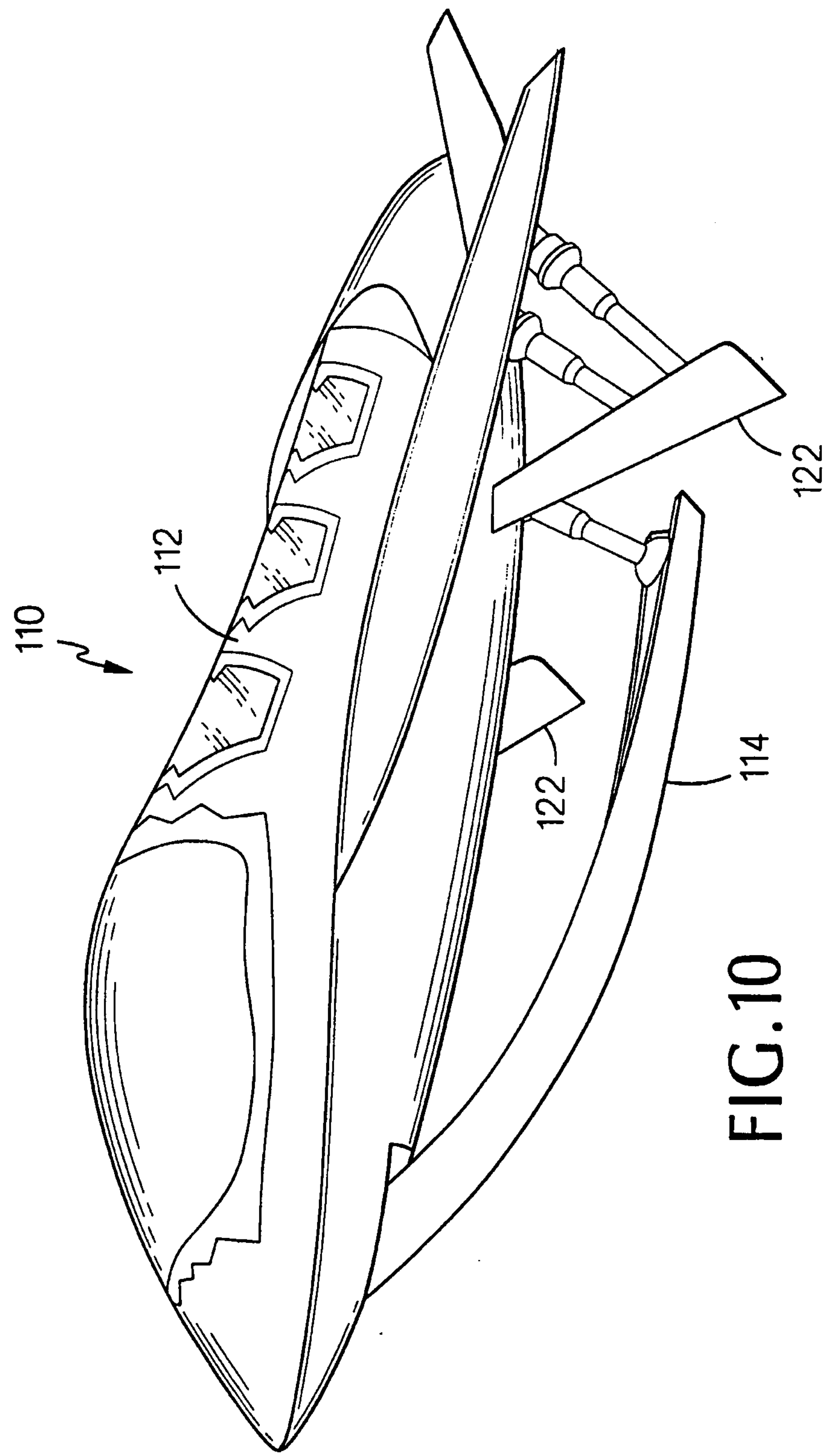


FIG.10

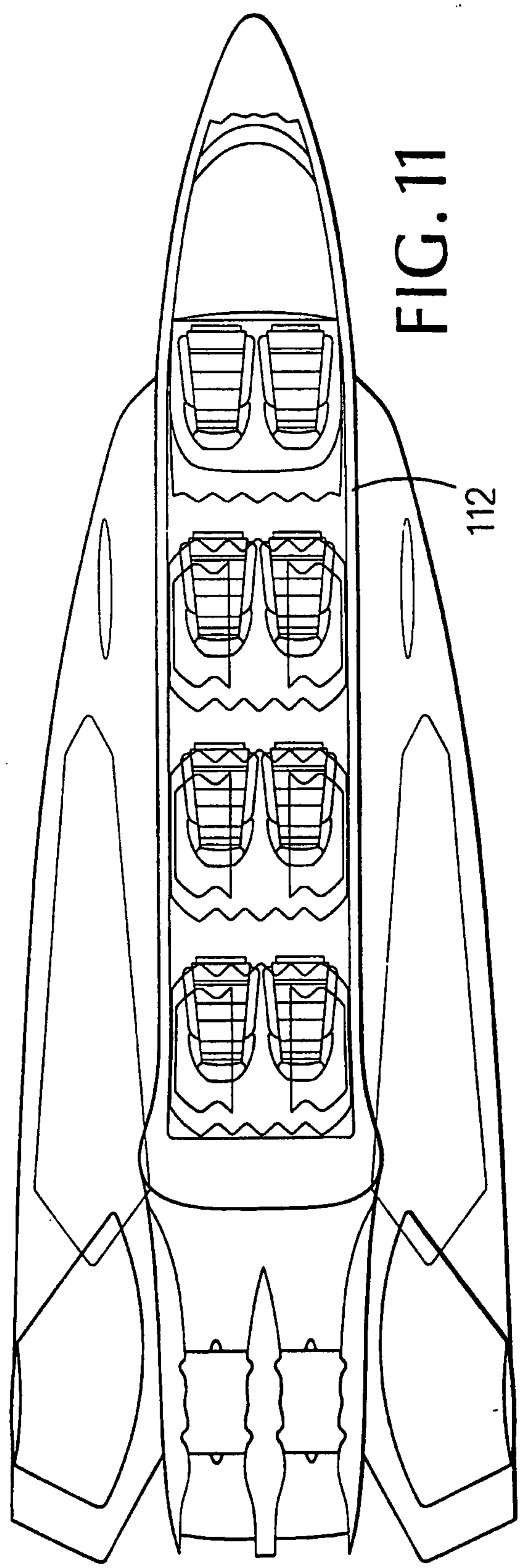


FIG. 11

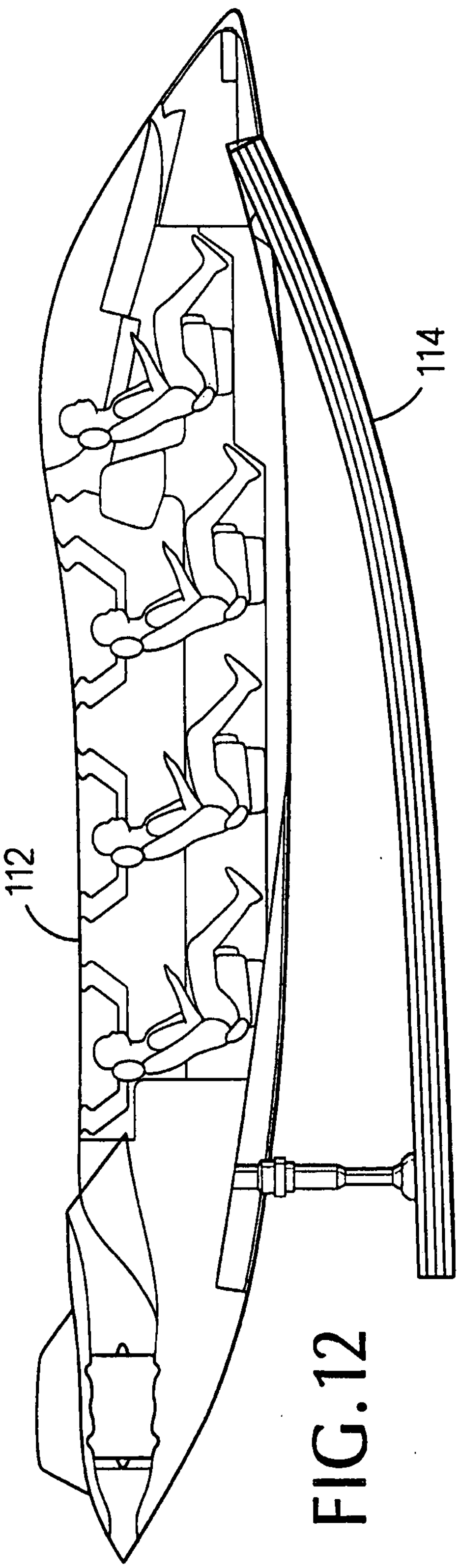


FIG. 12

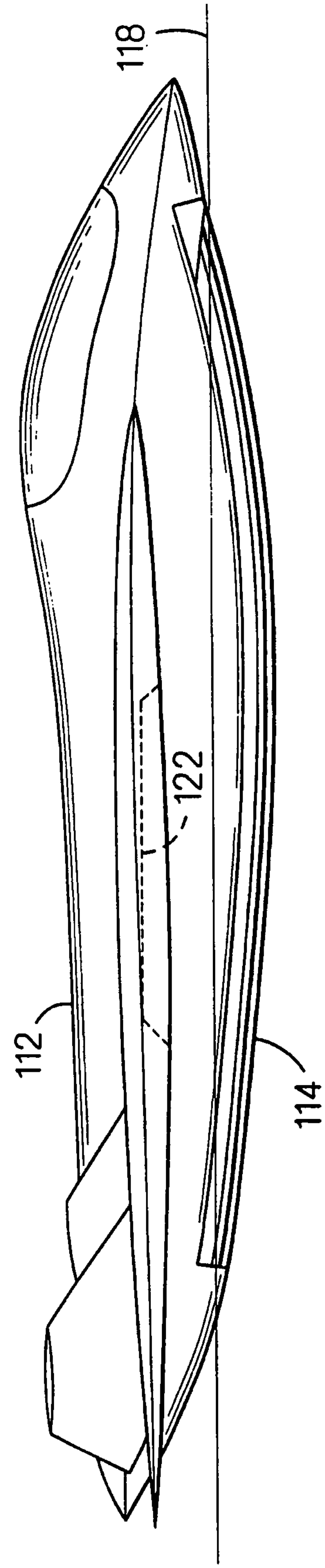


FIG.13

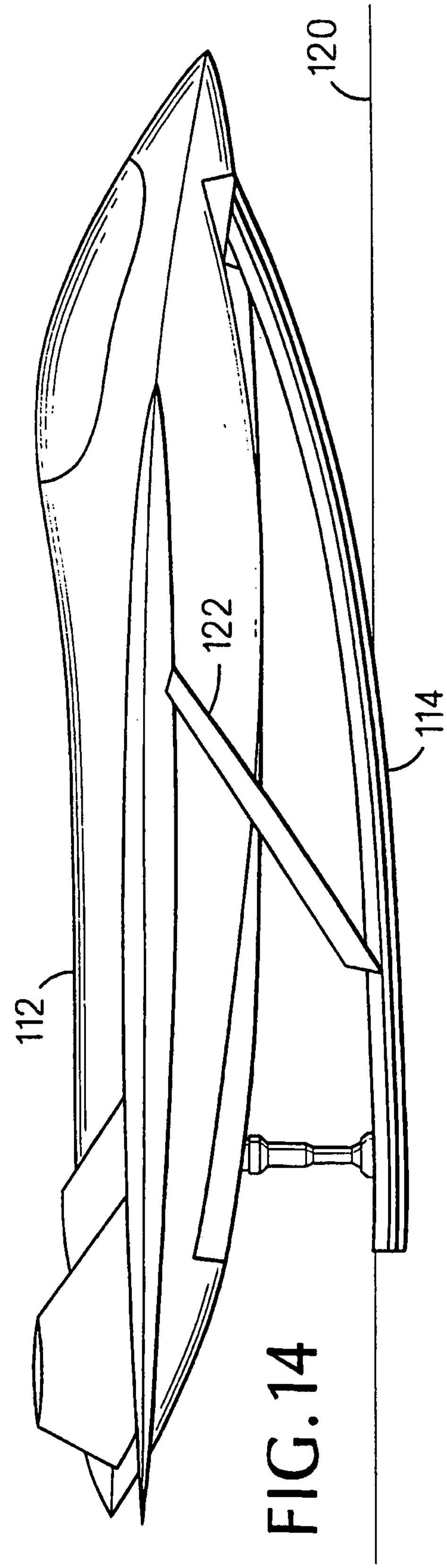


FIG.14

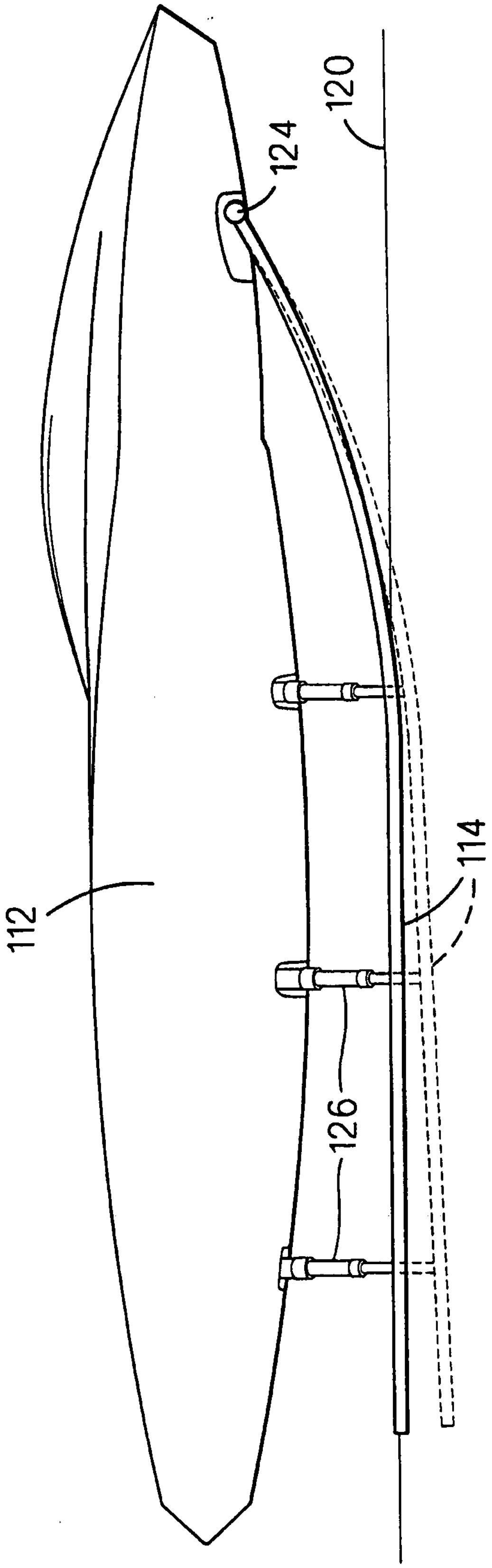


FIG. 15

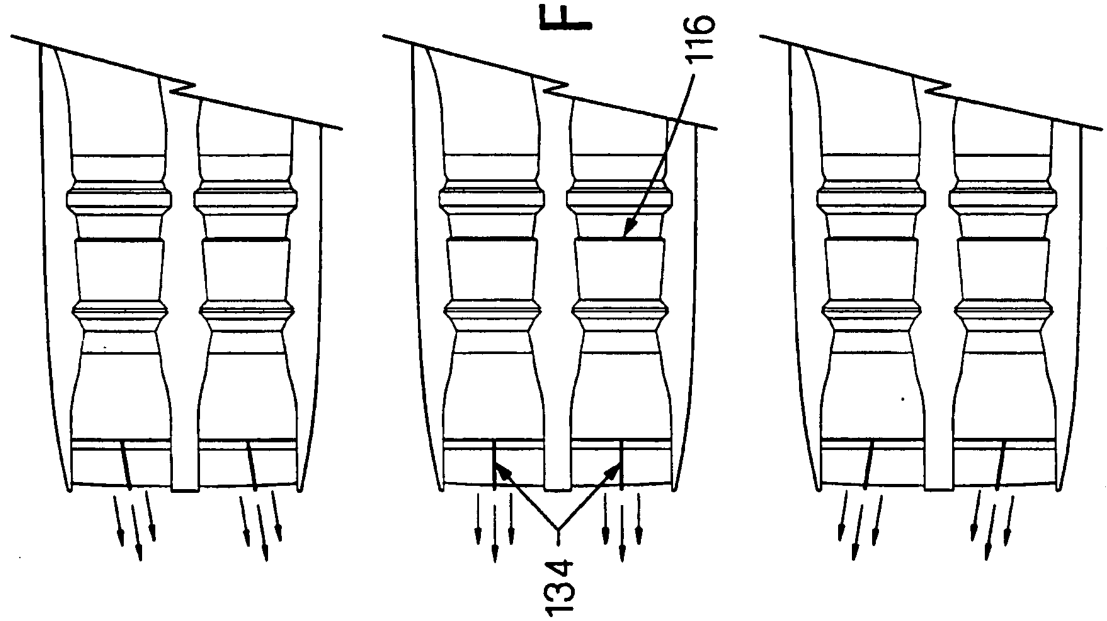


FIG.17

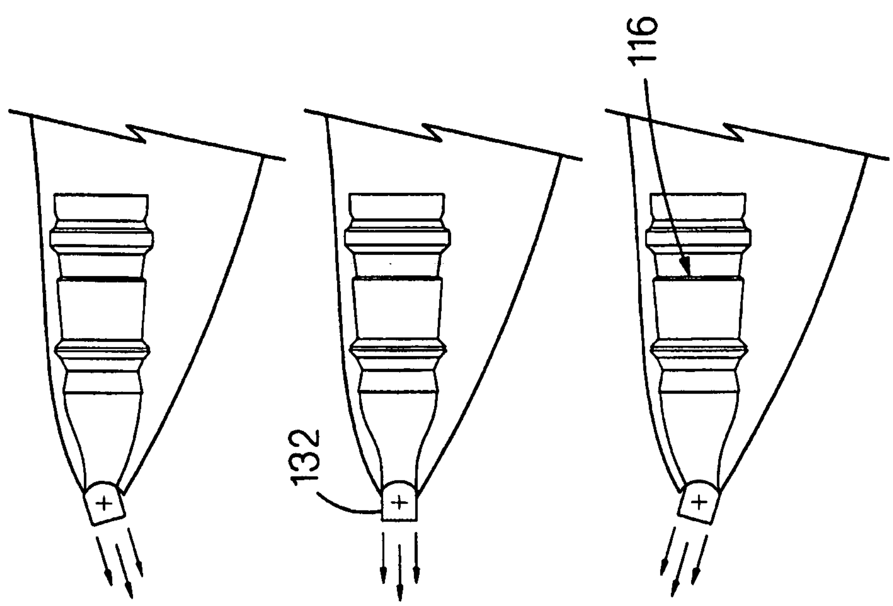


FIG.16

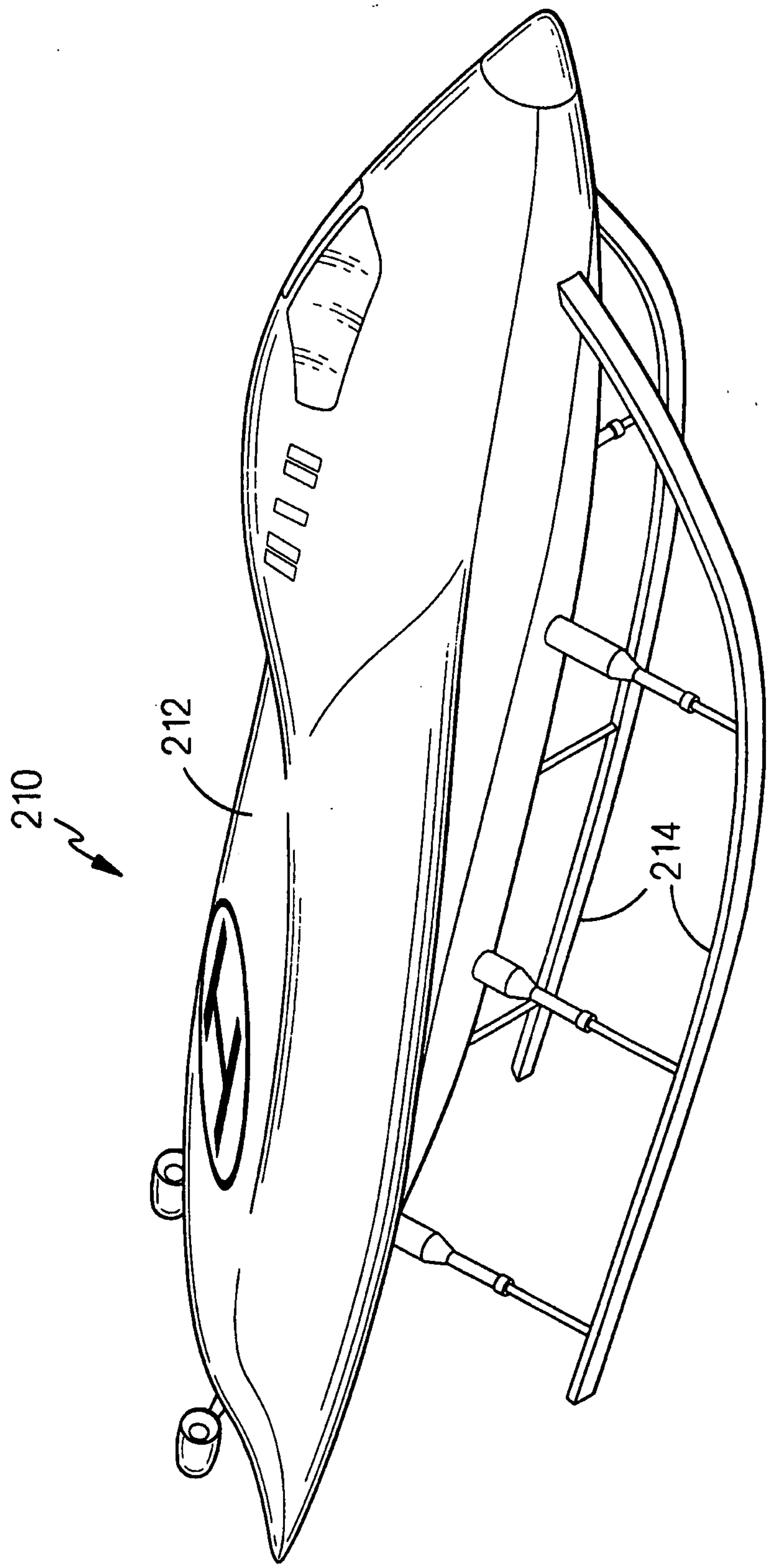


FIG.18

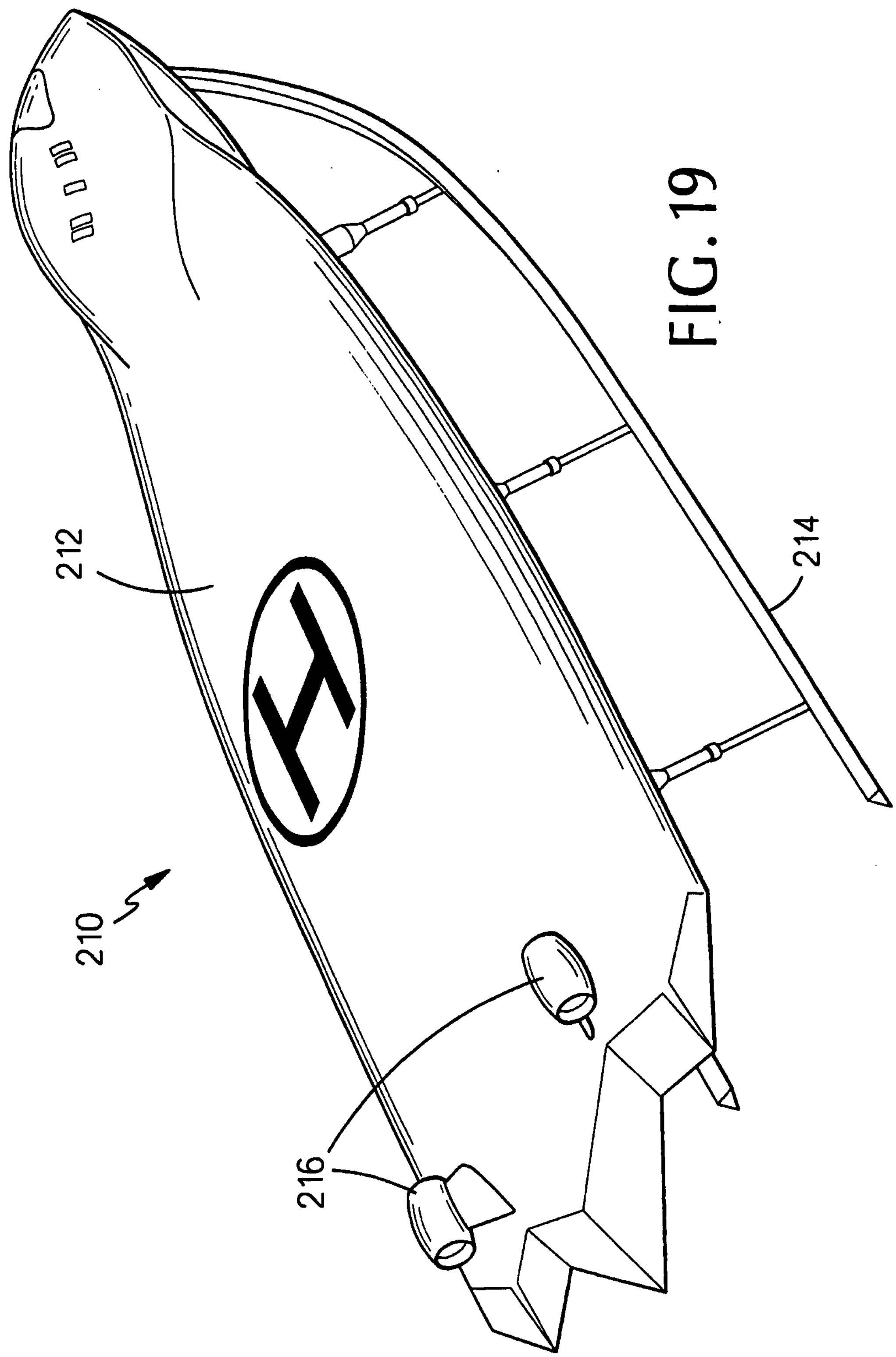


FIG. 19

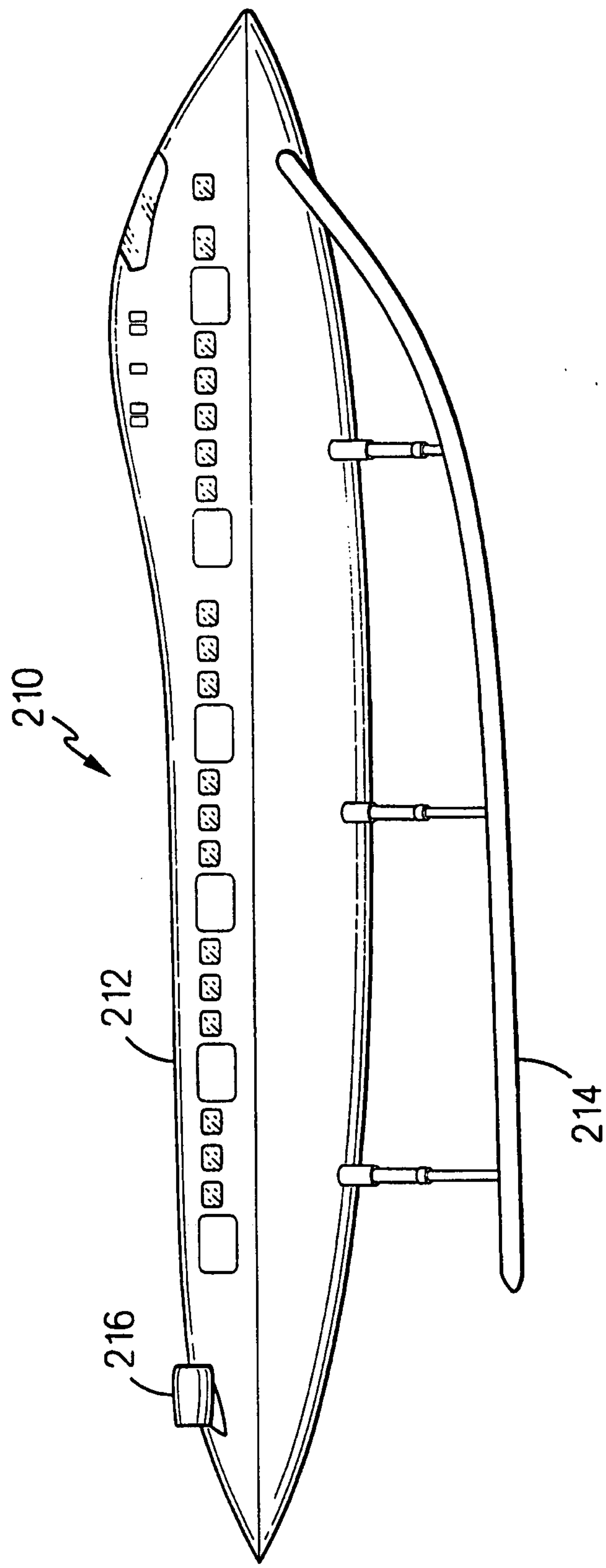


FIG. 20

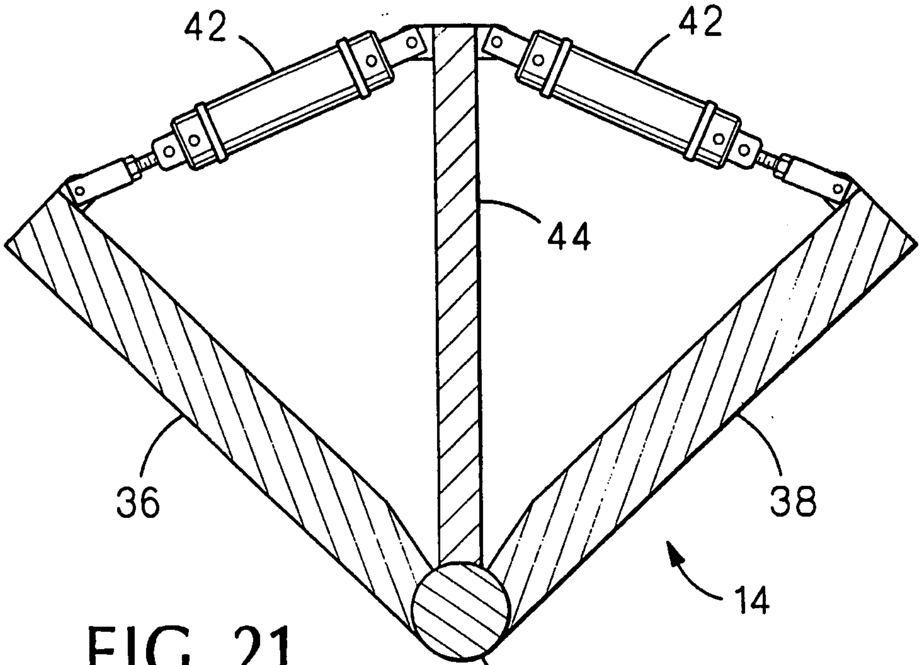


FIG. 21

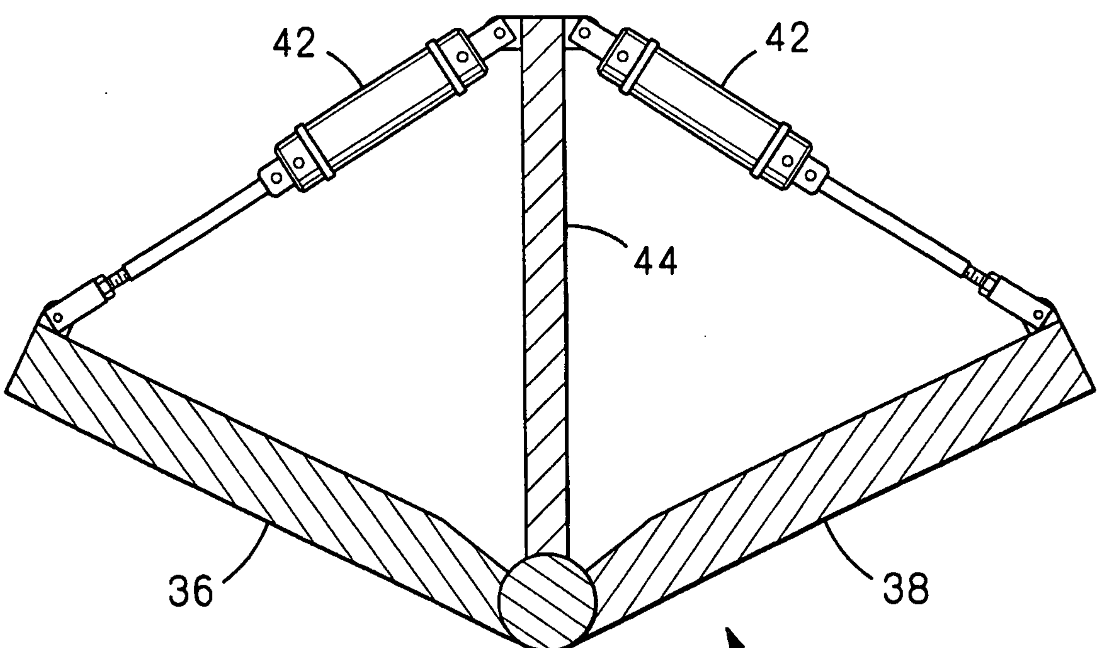


FIG. 22

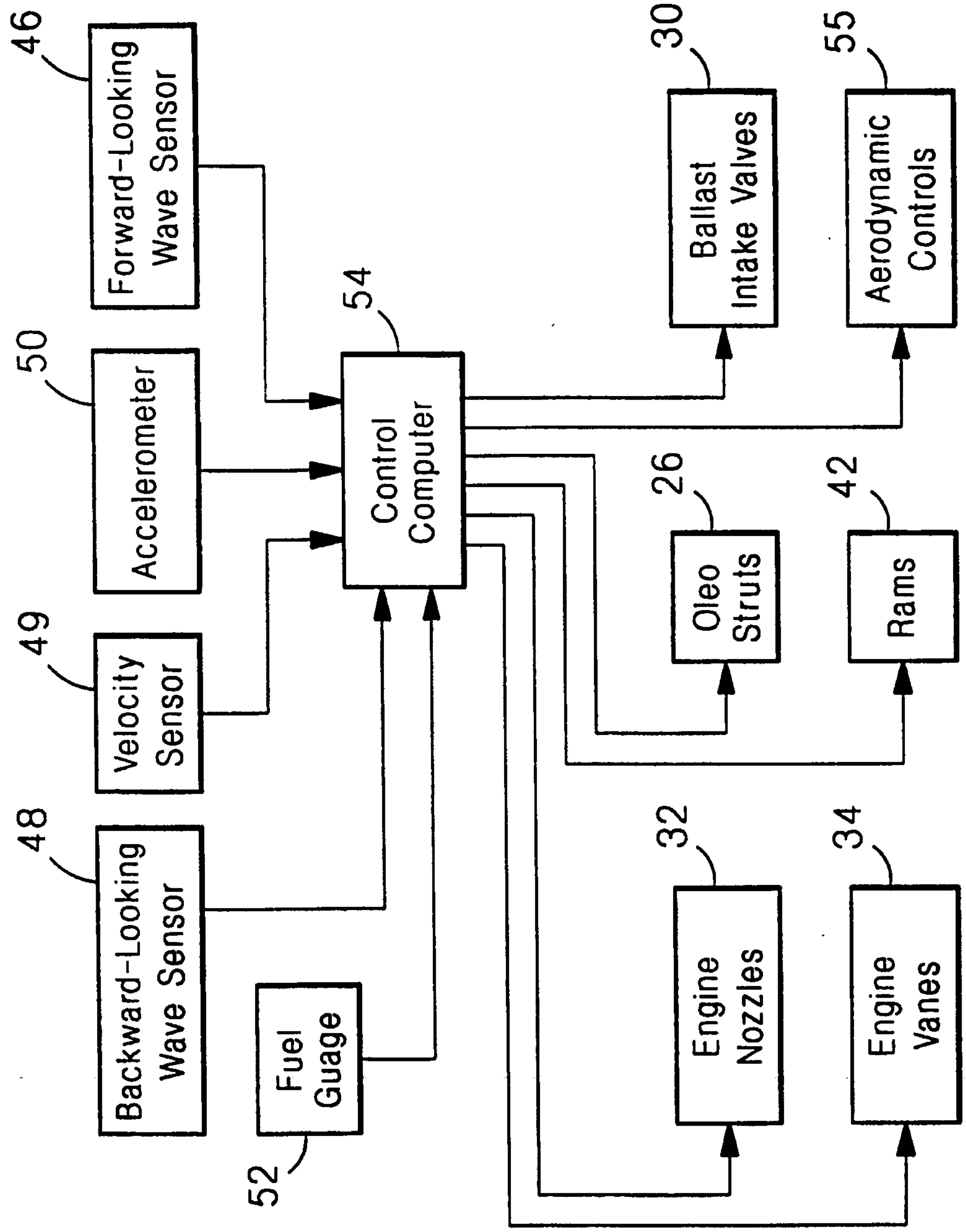

46
Forward-Looking Wave Sensor
50
Accelerometer
49
Velocity Sensor
48
Backward-Looking Wave Sensor
Fuel Guage
52
54
Control Computer
30
Ballast Intake Valves
55
Aerodynamic Controls
26
Oleo Struts
42
Rams
32
Engine Nozzles
34
Engine Vanes

FIG. 23

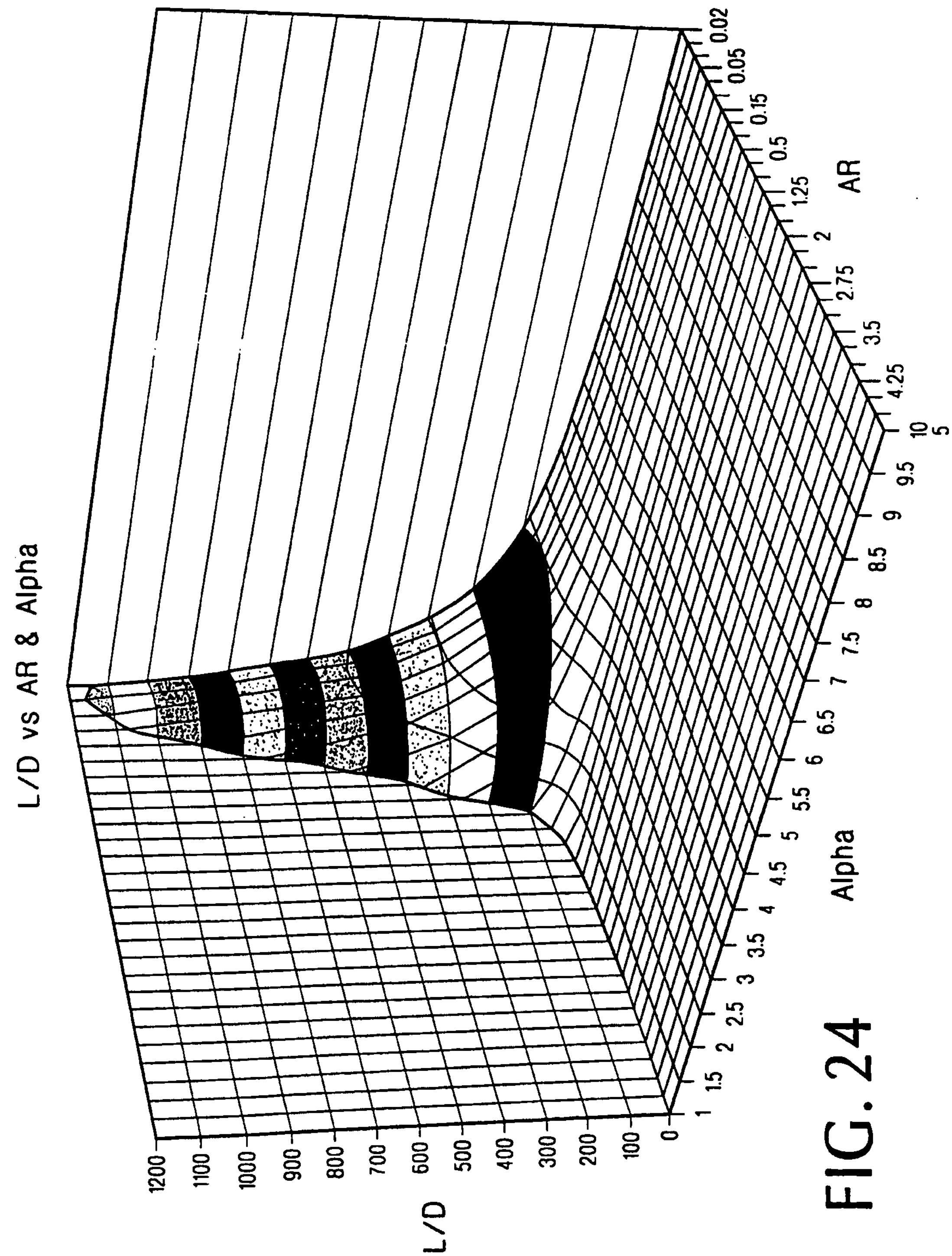

L/D vs AR & Alpha
L/D
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Alpha
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
AR
0.02
0.05
0.15
0.5
1.25
2
2.75
3.5
4.25
5

FIG. 24

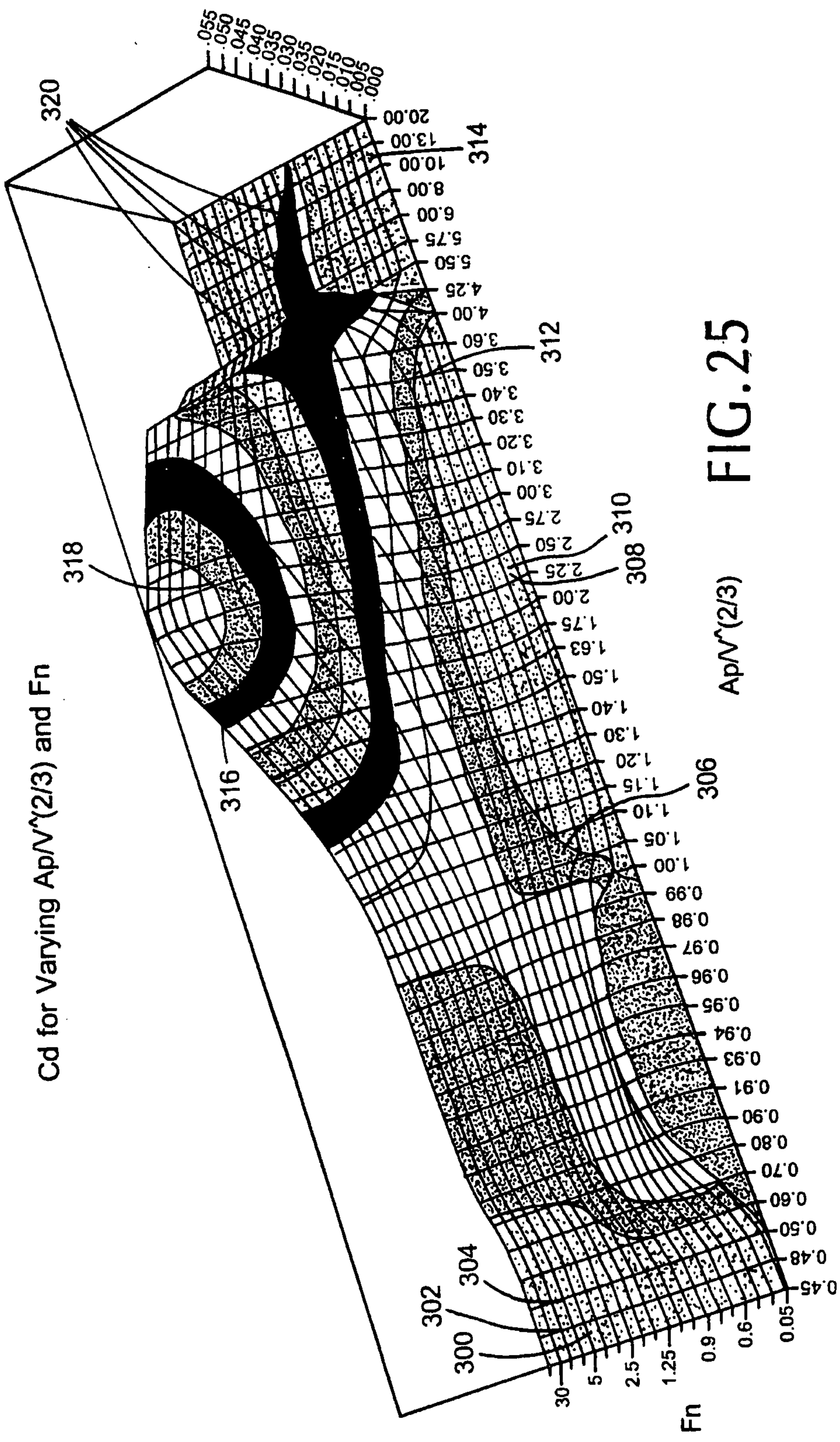

Cd for Varying Ap/V^(2/3) and Fn
Ap/V^(2/3)
Fn
.055
.050
.045
.040
.035
.030
.025
.020
.015
.010
.005
.000
20.00
13.00
10.00
8.00
6.00
5.75
5.50
4.25
4.00
3.60
3.50
3.40
3.30
3.20
3.10
3.00
2.75
2.50
2.25
2.00
1.75
1.63
1.50
1.40
1.30
1.20
1.15
1.10
1.05
1.00
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.91
0.90
0.80
0.70
0.60
0.50
0.48
0.45
30
5
2.5
1.25
0.9
0.6
0.05
300
302
304
306
308
310
312
314
316
318
320

FIG. 25

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/14987

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B63B 1/20
US CL :114/283
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 114/283,61,121,125,144e,270-278 440/38-42 D12/300,310

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ------ Y	JP 62-244,778 A (YUKIO KAJINO) 26 OCTOBER 1987 SEE ENTIRE PATENT	11,15, 21-24 ------ 1-3,5-8,12, 13,16-20, 25, 26
X ---- Y	US 5,619,944 A (BAKER) 15 APRIL 1997, SEE ENTIRE PATENT	11,14,20 ---- 1-8
X	US 5,265,550 A (HARPER, JR.) 30 NOVEMBER 1993, SEE ENTIRE PATENT	52-55,58, 59
X	US 4,685,641 A (KIRSCH ET AL.) 11 AUGUST 1987, SEE ENTIRE PATENT	52-56

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"B" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 NOVEMBER 1997	12 DEC 1997

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	ED SWINEHART
Facsimile No. (703) 305-3230	Telephone No. (703) 308-1113

INTERNATIONAL [redacted]CH REPORT

International a[redacted]on No.
PCT/US97/149[redacted]

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US 2,647,709 A (DOOLITTLE ET AL.) 04 AUGUST 1953, SEE ENTIRE PATENT	27,28 ---- 29-31
Y	US 3,987,743 A (PENSEL) 26 OCTOBER 1976, SEE ENTIRE PATENT	9,10,19,20,25,26 29,30
Y	US 3,157,146 A (BILLIG) 17 NOVEMBER 1964, SEE ENTIRE PATENT	31

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/14987

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 27-31,33-51 and 57
because they relate to subject matter not required to be searched by this Authority, namely:

The specification is objected to as failing to provide an adequate written description of the control arrangement of the thrust vectoring ystem and planing element supports responsive to sensed wave conditions.

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest [ ] The additional search fees were accompanied by the applicant's protest.
[ ] No protest accompanied the payment of additional search fees.